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THE ADVANCE IN ELECTRICITY
SINCE THE
TIME OF FRANKLIN

BY

JOHN TROWBRIDGE

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PREFACE

THE reader perhaps will ask "How can such a great advance be treated in a small volume?" There are, however, salient topics, apart from the discussion of the vast practical employments of electricity, which are of great intellectual interest to one who wishes to keep informed upon the progress of science. In discussing these epoch-making topics we can understand the importance of Franklin's work and find today a remarkable return to his theories of electricity: the prevailing electron theory resembles greatly his theory of excess and deficit of electrical charges. It is interesting, moreover, to reflect upon what barred his advance in the study of electricity and what a new world has been opened since his time; what infinite complexity has been found in what seemed comparatively easily comprehended phenomena — that of lightning, and the colors of the rainbow.

In his time these two impressive manifestations in the sky were supposed to be entirely unrelated. No one had the imagination to conceive that they were both electrical. There were those who dreamed of the transmutation of metals; there were philosophers who anticipated the modern atomic theory; but there was no one who at the time of Franklin conceived of any relation between magnetism, electricity, and light. Even the atomists thought of the motions of the particles of matter without any intimations of electrons.

In reading the various lives of Franklin, I have been struck by the absence of consideration of his greatest contribution to natural philosophy — his theory of an excess and deficit of electricity. His popular scientific reputation may be said to rest entirely upon his celebrated kite experiment. But among scientific men there has been due appreciation of his scientific work. Sir Humphrey Davy said that a singular happiness of induction guided all of Franklin's researches; he established very great truths by extremely simple means. Among literary men Sainte Beuve, in his *Causeries de Lundi*, was the most appreciative of Franklin's scientific mind.

Franklin's prestige in France was due more to his researches in electricity than to any other cause. He did not rank as a master in diplomacy among the most skilled diplomats of the time; he was not recognized as a mental philosopher and writer by a nation which has always considered itself supreme in the fields of literature — a nation which had at that time Voltaire; moreover, he came from the Provinces. It can be said that, "He hitched his wagon to a star." Lightning flashes seen by every one in terror spread his name on the heavens, and Condorcet's words, *Erupuit fulmen caelo, mox sceptra tyrannis* (he snatched lightning from the sky, and afterward, sceptres from tyrants), established his fame among all classes — the rarest fortune of a scientific man.

Franklin was fortunate in receiving such fame for his scientific work in a country which was preëminent in both science and literature, and this reception probably led to his statement that he desired to abandon diplomacy and public life and to devote himself to the study of electricity. We realize, now, that his further work in this field would not have been fruitful, for the electric current and its effect upon magnetism was not discovered until after his death: he had not in his power fundamental means to advance the subject. The centre he had created of electrical research in America shifted to Italy, where a new world in electricity was discovered. Franklin's work may be said to have paid back to the old world the debt America owed for the discovery of its continent.

In a limited space I have sketched the state of Franklin's mind in regard to the singular phenomenon of the existence of attracting or repelling charges of electricity; and I have endeavored to show that the latest theory in electricity — the electron theory — closely resembles his theory of excess and deficit. While his philosophical views of the phenomena of electrical sparks are largely accepted, his experiments cannot be said to have led the way to practical employments of electricity. Their lack of influence on a great future development was due to a want of perception of the relations of magnetism to electricity. Franklin's advance in his favorite subject was completely barred by an ignorance of these relations. I have quoted his words to show how feeble he considered the manifestations of magnetism in comparison with those of electricity. A giant was lying concealed in his workshop. All our great advance in electricity since the time of Franklin has been due to the increase of our knowledge of magnetism. After we have considered the wonderful phenomena of radium we may be led to ask: are not the manifestations of magnetism still more wonderful?

I have supplemented Franklin's study of lightning in the sky by a laboratory study of the nearest approach to this manifestation which has been made; and in addition to the means he employed to study electricity I have employed the method of the revolving mirror which has revealed the possibility of tuning in wireless telegraphy. My treatment of the advances in electricity since the time of Franklin is included under the following: lightning in its general aspects; the dynamo which has so to speak brought down lightning from the skies; the discovery of the electron and its influence upon our views of matter — our increased appreciation of the immense and the infinitesimal; the influence of electrical discoveries on some phases of contemporaneous thought; and the embracement of all the divisions of electrical science under the one head, energy.

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THE ADVANCE IN ELECTRICITY SINCE THE TIME OF FRANKLIN

CHAPTER I

ELECTRICITY AND ENERGY

IT is now fifty years since Tyndall's work, entitled *Heat as a Mode of Motion*, was published. It had immediately a great effect in stirring men's minds to a realization of the importance of the conservation of energy. The basis of the book consisted of a course of lectures delivered before the Royal Institution in London, characterized by clear and picturesque language, and well chosen experimental illustrations which often partook of the simple character of Count Rumford's celebrated experiment, which showed that the work exerted in boring a cannon had its exact equivalent in the heat produced.

Tyndall also wrote a treatise on light, in which there is no intimation of the relations of light, heat and electricity and of a possibility that another great theory would make electricity the corner stone in the edifice of physical science. It had been proved that energy comes to us from the sun in electrodynamical waves: those of light are the shortest; those of heat longer; and those of electricity the longest. When these waves strike the particles of matter they cause exhibitions and transformations of energy. Indeed, the science of physics can be defined as the science of energy. What an immensely broader field the writer of a popular treatise must cover than that surveyed by Tyndall! Such a writer is relieved, at least, from a discussion of the country of origin of the electrodynamical theory of heat and light: it was England; and the theory sprang from the brain of Clerk Maxwell.

The success of Tyndall's book was greatly due to his illustration of the relation of familiar facts to the theory of the conservation of energy: for instance, in speaking of expansion, he presented to the audience two tightly corked bottles filled with water, and after placing them in a freezing mixture, he said, "These atoms are giants in disguise; you hear that sound; the bottle is shivered by the crystallizing molecules; there goes the other! and here are the fragments of the bottles which show their thickness, and impress upon you the might of that energy by which they are risen. You have now no difficulty in understanding the effect of frosty weather upon the water pipes of your house. I have here a number of pieces of such pipes, all rent." Again, he says, "You see this iron rust, produced by the falling together of the atoms of iron and oxygen; but though you cannot see the transparent carbonic acid gas, it is formed by the union of carbon and oxygen. These atoms, thus united, resemble a weight resting upon the earth; their mutual attraction is satisfied. But I can wind up this weight and prepare it for another fall, even so these atoms can be wound up, separated from each other and thus enabled to repeat the combination." Tyndall could appeal to the observation of even his unscientific hearers on the effects of heat and light; on the deportment of water, the effects of rainfall; the movement of glaciers. He could carry his hearers and readers with him in the question of the maintenance of the sun and the relation of its heat to the continuance of life. These topics have a vital interest to every man. The writer, however, of a popular treatise on the prevailing views of electricity cannot select such a wealth of homely illustration. He can speak, it is true, of lightning which is a phenomenon recognized by every one; he can describe the dynamo only, however, as a generator of light and power — not in respect to its scientific working. He can speak of magnetism in a general way: its use, for instance, in the compass; but when he comes to the effect of magnetism in diverting the paths of electrons he gets far beyond the comprehension of the average man. Heat and light cause phenomena which can be investigated by comparatively simple means: by the sensitiveness of the human hand to changes of temperature; by even the unaided eye. To comprehend, however, the manifestations of electricity we need complicated instruments. Franklin went so far as it was possible in his day without a galvanometer: it is as if Tyndall had studied manifestations of energy chiefly in a lowland while the student of electricity today is in a mountain range, considering the immense energy which can be obtained from waterfalls which by electrical transformations can completely change systems of lighting, heating, and methods of transportation.

In the study of the phenomena of heat, I have said: The eye, even unaided, can greatly serve for our comprehension of phenomena; even the impact of invisible molecules is in evidence by the increase of pressure of a gas under the influence of heat, but in the study of the particle of electricity, the electron, we need the most refined instruments to detect the vibrations of movements of the smallest object known to science. The movements of molecules under the influence of heat are far simpler than the movements of electrons. Molecules of a gas under heat excitement fly in straight lines, collide with each other, are not influenced by a magnet; they have no orbital movement; electrons, on the contrary, have such movements; they are greatly affected by magnetism, and exhibit magnetism themselves. They are supposed to leave a wake in the ether of space as they fly with prodigious velocity; they cause electromagnetic waves in their progress, or when they fly apart from common matter. A lighted match or candle emits electromagnetic waves, and is thus a minute image of the sun.

It is an interesting question to ask if Tyndall were living today, and if a publisher should ask him to bring his book up to date, what title would he give to it? He certainly would not retain the title *Heat as a Mode of Motion* nor would he, in view of the all-embracing nature of electricity, term it *Electricity, a Mode of Motion.* The extension of our views of energy would require for its popularization all his power as an eloquent expounder. We have made an astonishing advance since his time: the subject of physics has broken away from comparatively narrow limits and has made even chemistry and biology a part of it. The physicist has discovered that all the life of the world depends upon electromagnetic waves of energy which come from the sun. The physicists today may be called sun worshippers, and like priests of an ancient cult, bow with humility before a deity, when they reflect that barely a millionth part of the sun's energy reaches the earth. The rest ripples through space and together with the enormous amount of energy emitted from other suns apparently has no equivalent in transformations which we can study.| The planets take a very small proportion; the ether of space, perhaps, absorbs a trivial amount, and no relation has been found between electromagnetic waves and gravitation. The earth is a mote floating in space. To an observer at the probable limits of this universe it might seem like an electron shot off from radium. The imagination of such a distant observer would be severely taxed to conceive of the varied life on such a mote; yet the physicist on the mote conceives of a world of motion in the infinitesimal electron which may be said to make a part of this mote.

It is certain that we receive energy from the sun, and we are made conscious of its waves only by their excitation of atomic and electronic motion. Electricity a thousand miles above the surface of the earth exists only as an invisible ripple. It is incontestible that the waves progress like waves on water: a cork on water moves up and down in a direction at right angles to that of the progression of the waves. In space electricity manifests itself in the mind of the physicist simply as wave lengths. The mathematical consideration of these waves is comparatively simple until they strike matter: when one attempts to deal with their manifestations with matter one has need of the most abstruse analysis; and the writer of a popular treatise on electricity cannot state his conclusions clearly without the use of mathematics. It is needless to say that if he employed them his treatise would not be popular; yet words have not the conciseness of mathematical expressions. In the discussion of the problems: how do the electrons move in the case of the electric current, what is their function in the performance of the dynamo, why should the movement of a conductor near a magnet produce an electric current? — the writer of a popular treatise is, as Faraday said of the popular lecturer, compelled to conceal the difficulties. Tyndall spoke chiefly of the relations of heat to motion. In a treatise on electricity we have to illustrate the connection between the four great divisions of the subject of energy — heat, light, electricity and magnetism. Fifty years ago the phenomenon of lightning represented electricity to the common mind: today the dynamo with its production of light, heat and motion has taken the place in popular apprehension, of lightning. Our minds have been brought down from a contemplation of the skies to the earth. The manifestation of energy in the heavens may be said to have led physicists to consider their subject, under the one head, energy.

CHAPTER II

LIGHTNING

IT would seem that little more can be obtained from the study of lightning than Franklin obtained; for we cannot establish a laboratory in the skies; and we cannot repeat, except on a small scale, the phenomena of discharge of electricity in the atmosphere; moreover, what is the practical use of the study of lightning? One can answer that wireless telegraphy has resulted from the study of electric sparks. Lightning in its realm will probably always remain secure from scientific intruders, even from those who fly in aeroplanes; and there seems to be no hope of harnessing it for practical purposes. To attempt to do so would be like attempting to control the outbreaks of a volcano.

In a thunder storm the most apathetic person is apt to seek information from one who is supposed to be able to supply it. Both the scientific man and the literary man are mentally in accord in the contemplation of the marvellous spectacle of lightning: it is a most compelling sight! winds have their functions; excessive heat leaves a permanent impression on vegetation; but the electricity of storms is apparently an ebullition of nature which passes often without any effect upon the earth, except in an occasional stroke — local in its nature. The function of lightning today seems to be that of lifting man's mind to a consciousness of the immense energy which is exhibited in the rearrangement of invisible atoms and electrons. If lightning did not occur the era of practical employment of electricity would probably have dawned; the discoveries of the battery and electromagnetism were not suggested by the phenomenon of lightning. Jupiter's thunderbolts can no longer be thought instrumental in affecting the state of man: the Promethean tradition seems to have been a forecast of the coming of the dynamo with its conversion of electricity into heat.

In an introduction to an edition of the *Prometheus Unbound* of Aeschylus, Professor Allen of Harvard University says, "To the mind of the savage man, the generation of fire, when a tree is struck by lightning from the sky, or by a spark elicited from a piece of wood by friction, is not simply a marvel, but a miracle. Fire is the celestial agency which aids man in all the arts of life in whatever he fashions and creates. The possession of fire, and the knowledge how to use it in the preparation of food and the practice of the mechanic arts, lifts a community of savagery and advances it to a life of culture and comfort. As man advances, grows in independence, in self-consciousness, as he feels in himself the ability to guard against misfortune by his own prudence, as his standard of living and thinking is raised, he becomes aware of a distinct break with his past life — its uncertainties, its hampered conditions and its narrow horizon. What formerly he expected from the grace of the gods, and sought to obtain through sacrifices, he now believes he can get by his own skill. Accordingly this transition from barbarism to civilization comes to be associated with the idea of a Titan-like struggle on the part of men to make themselves equal to God — with the notion of a curtailment of divine privileges for the advancement of the human race, and of defiance and revolt against the gods. "Out of these conceptions the story of Prometheus has gradually grown."

In the presence of a thunder storm the scientific man and the literary man, I have said, come into close communion. The scientific man can hold the attention of even unscientific hearers while developing the theory of the minute electron which is a part of the tremendously great exhibition of lightning; and the literary man can be interested in references to lightning in literature. It is a remarkable fact, however, that lightning fails to keep up a constant interest in electricity among literary men and is compelled each spring and early summer to recreate a vivid interest. King Lear's question "What is the cause of thunder?" is not yet fully answered by the philosophers; but it is hoped that my laboratory experiments, which are, perhaps, those carried on on the largest scale hitherto, may tend to answer this question.

CHAPTER III

PROTECTION FROM LIGHTNING

WHEN we enter upon a scientific examination of one of the greatest manifestations of energy in nature, we naturally think first of Benjamin Franklin. His dramatic act in drawing lightning from the clouds is related to every school boy; but few Americans know the bearing of Franklin's theory of electricity upon the electron theory which now prevails: this bearing I hope to make clear. In the first place, let us examine the prevailing views and superstitions of the common man in regard to lightning and his attitude toward the lightning rod. It is now one hundred and seventy odd years since Franklin advocated the use of pointed rods to draw electricity from the clouds, and Dalibard tried an experiment with such rods in Paris. Franklin did not wait for the erection of a rod in Philadelphia but flew a kite provided with a metallic point, and held by an ordinary pack thread, during a thunder storm. At the end of the pack thread a silk thread and a key were attached: the silk thread was attached to a tree. For a time no effect was observed, and Franklin began to despair of success; presently, however, the string being wet, he presented his knuckles to the key and received a spark. Thus was made the most renowned experiment in electricity. Perhaps he got merely a wireless message from a distant lightning flash, for the kite and string may have served as an aerial for a pulsating inductive effect: indeed such effects occur during thunder storms on telegraph and telephone wires. I mention this as a possible interpretation of the result he obtained, but not to belittle his achievement. If he did not actually draw down lightning from the clouds he proved the identity of atmospheric electricity with that furnished by electrical machines. The simplicity of his experiment has given him enduring fame. The result, however, of the kite experiment was small in advancing the science of electricity: it did not lead to further research and its principal fruit was the lightning rod which has not answered the expectation of Franklin. His most valuable work is not generally known and consists in his philosophical views of electricity. But he firmly believed in the efficacy of his lightning rod and was supported in this belief by many scientific men of his time. John Winthrop Hollis, professor of mathematics and natural philosophy in Harvard College, wrote to Franklin on January 6, 1768:

"I have read in the *Philosophical Transactions* the account of the effect of lightning on St. Bride's steeple. It is amazing to me, that after the full demonstration you had given of the identity of lightning and electricity, and the power of mettaline conductors, they should ever think of repairing that steeple without conductors. How astonishing is the force of prejudice, even in an age of so much knowledge and inquiry!"

The old buildings of Harvard College still have traces of lightning rods which were erected in the latter part of the eighteenth century. Their installation shows how little even scientific men of that time realized the energy manifested in an ordinary lightning discharge. None of the later buildings of the university are provided with rods except the Jefferson Physical Laboratory. I will give, later, a description of the arrangement of rods on this building; for it illustrates the present attitude of successors to John Winthrop toward Franklin's invention. It is evident that Franklin could not regard the doubts of scoffers with equanimity. Perhaps his state of mind was expressed in the words, "One should not of all faculties or qualities of the mind wish for a friend or a child that he should have that of invention. For his attempts to benefit mankind in that way, however well imagined, if they do not succeed, expose him, though very unjustly to general ridicule and contempt; and if they do succeed to envy, robbery, and abuse."

The race of lightning rod men has almost entirely disappeared. They once, during the early part of the nineteenth century, besieged every householder. An age of scepticism has crept in, but with a certain tolerance expressed by the remark of a farmer in regard to lightning rods, "that their intentions are good." There is still, however, a lurking belief in the public that protection from lightning can be obtained by some modification of Franklin's plan. This belief prevails especially during the terrifying exhibitions of a thunder storm. Franklin thus suggests precautions for safety to those who have not provided lightning rods for their dwelling: "Persons apprehensive of danger from lightning, happening, during the time of thunder to be in a house not so secured (by lightning rods) will do well to avoid sitting near the chimney, near a looking glass, or any gilt picture or wainscot. The safest place is in the middle of the room so as it may not be under a metal lustre suspended by a chain sitting in one chair and laying the feet up on another. It is still safer to bring two or three mattresses or beds into the middle of the room and folding them up double, place the chair upon them; for then, not being so good conductors as the walls, the lightning will not choose an interrupted course through the air of the room and the bedding when it can through a continued better conductor, the wall. But where it can be had, a hammock or swinging bed, suspended by silk cords equally distant from the walls on every side, and from the ceiling and floor above and below affords the safest situation a person can have in any room whatever, and may be deemed quite free from danger of any stroke of lightning."

The electrician of today might subscribe in part to this advice, but he would make certain criticisms: one would be that the strength of possible lightning discharges might overcome the safeguards he recommends. Would Franklin have tried his celebrated experiment if he had fully realized the potentiality of lightning? The same criticism an electrician might make of Franklin's advice to Mr. Peter Franklin at Newport, on the best method of securing a powder magazine from lightning.

"You may acquaint the gentleman that desired you to inquire my opinion of the best method of securing a powder magazine from lightning, that I think they cannot do better than to erect a mast not far from it, which may reach fifteen or twenty feet above the top of it, with a thick iron rod in one piece fastened to it pointed at the highest end, and reaching down through the earth till it comes to water. Iron is a cheap metal; but if it were dearer than this in a public thing, the expense is insignificant; therefore I would have the rod at least an inch thick to allow for the gradual wasting by rust; it will last as long as the mast, and may be renewed with it, the sharp point for five or six inches should be gilt."

It has been discovered that lightning is not so easily confined to a single path. The air surrounding a powder magazine is not homogeneous and free from currents, and cannot be ionised, as we now say, more readily in one path than in another. The theory of ionisation can be best understood when we have considered the electron theory: currents of heated air seem to have an effect in directing lightning discharges: barns are often struck even when near tall trees. Frequently the discharge enters through an open door or window. Air heated from hay — and there are few places that can be hotter than hay mows — flows out and forms avenues of least resistance to lightning. The only complete protection seems to be in a Faraday cage, which is a metallic covering completely enclosing a dwelling or structure. A person inside such a cage can be completely shielded from electrical disturbances. It is, however, not practical to enclose entirely a building in a close metallic cage, but it is possible to approximate to such a covering. A room can be furnished with metallic nettings; the walls covered with them; the netting connected to water pipes or moist centre. Powder magazines frequently have such protection. Rooms so shielded should not contain large masses of metallic masses such as stoves; if these are present they should be connected to the wire cage. Dreadnoughts have the equivalent of such cages in the metal construction of their hulks. Although we cannot protect a large building by a metallic cage, we can use to advantage what may be called a skeleton. The physical laboratory of

Harvard University furnishes such an example. A copper conductor runs around the eaves; this is connected to pointed rods which rise to the tops of the chimneys. The conductor on the eaves is connected to rods which descend from the roof to the earth. There is thus a parallelogram on the roof joined by conductors to a parallelogram under ground.[1] The terror that some people feel in thunder storms is so great that the construction of a netted room would seem to be advisable for them. Many such terrified persons put their faith in insecure safeguards, such as chairs with glass legs, feather beds, and closed windows. It is true that there are cases on record of individuals being struck while standing at open windows or doors. It may be that heated currents of air direct the discharges of electricity. Personally I am tempted to retire from such openings; and I am confident that it is unsafe to take refuge under trees — a discharge of lightning evidently finds a heated human body a better conductor to the ground than the comparatively unwetted bark of the trees. Movements of air are factors, evidently, in the selection of paths by lightning. These movements are influenced by heat.

Although there is no perfect defense from the danger of lightning to persons or buildings, one is able to guard against damage to telephone, telegraph lines and to dynamos. The possibility of lightning entering a house by means of wires is obviated by arresters, which consist of metallic points placed close to the leading-in wires in order to provide an easy passage of the electricity to the earth. The lightning prefers to jump across a small air gap to the task of overcoming the resistance of an electrical circuit. To increase still further the obstacles on the line coils of wire, called choking coils, are frequently used to protect electrical machinery from being burnt out by lightning. These coils act by induction or electrical inertia.

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[1] The laboratory was struck in 1920 but was not injured.

CHAPTER IV

SUPERSTITIONS IN REGARD TO LIGHTNING

WHILE the increase of wires in a city lessens the danger from lightning by providing many passages to the ground, the conductors carrying commercial currents into buildings may act in a malevolent way: when a lightning discharge takes to such wires, seeking a passage to the ground, and jumps from one wire to a neighboring one, it affords a passage for a strong electric light current, since electric sparks afford little resistance; the lightning short-circuits the dynamo current, and the latter therefore may cause a fire. The remedy for such an accident is in providing the commercial circuit at certain points with a length of fusible wire which will burn out when the current rises to abnormal proportions and will thus stop it. I was once walking in a corridor of a hotel during a heavy thunder storm and heard the crackle of an electric spark coincident with a lightning discharge: immediately the electric lights in the corridor were extinguished, having been burned out by a powerful dynamo current which had found an easy passage from one part of its circuit to another. This is a danger, however, which can be obviated by proper placing of fuses. There is another interesting safeguard against this indirect danger from lightning to buildings: this consists in placing a powerful magnet near a place where it is feared that lightning might facilitate the short-circuiting of a dynamo current. The magnet in common parlance is said to blow out the current which is established — the strong dynamo current and not the lightning spark upon which the dynamo current may be said to ride.

There are many superstitions in regard to lightning: these superstitions are rife among lightning rod promotors who often claim that the rods should be insulated from the protected building by glass insulators; these are speedily wetted by the rain, and, even if dry, would not be respected by a lightning flash which can leap many feet, and therefore, would not be restrained by a few inches of glass. Iron rods are recommended by some from a belief that iron through its magnetic qualities has a peculiar power of attracting lightning. This is not true.

Emerson, in speaking of the qualifications of a poet, says, "Like the lightning rod he must reach from a point nearer the sky than all surrounding objects, and into the wet soil, or neither is of use." This is epigrammatic but not scientifically correct in regard to the disposition of lightning rods: the influence of bodies below the highest point of a building, such as the relative size of bodies, movements of air, and what is termed electrical inertia or induction, have a most important effect in determining the course of a lightning flash.

The increase of telegraphic and telephone wires in and about cities lessens the danger of damage from lightning in thickly settled districts. Trolley cars have been struck, but rarely; when they are struck the danger will arise chiefly from the panic of the riders. Numerous statistics have been gathered in regard to the kinds of trees struck: it has been concluded from such statistics that poplars, oaks, and conifers are the most liable to be struck. Conditions of moisture and of soil, however, have far more influence than botanical species. Thunder storms generally follow the course of rivers: there are some localities which are remarkably subject to thunder storms, from the general configuration of the landscape. In these places properly placed lightning rods may avert damage.

In common with all great convulsions of nature, the phenomena of lightning have given rise to many fallacious beliefs and superstitions which are not confined to the uneducated. Even scientific men have told me that they can determine whether a lightning discharge passes from the sky to the earth, or in the opposite direction. We read in textbooks on electricity of descending and ascending flashes. There are both kinds; but the eye is unable to distinguish the direction. My apparatus for producing powerful discharges enabled me to prove this assertion. The terminals between which sparks six feet in length passed were shielded from the observer — for the appearance at the positive terminal is different from that at the negative. The discharge was vertical, and the observer was requested to note down what he supposed was the direction of the sparks. Meanwhile I changed this direction without his knowledge — interchanging the positive and negative terminals. I kept a record of these changes, and found no agreement between my records and those of the observer in a hundred trials. The eye cannot determine the direction of an electric spark.

The belief of certain persons that they are endowed with a high electrical condition proved by their ability to give sparks to people, to light gas by presenting a finger, or even to cure ills, is due to their wearing silk garments or to scuffling over dry carpets.

It is often reported that figures have been found imprinted upon the human body after thunder storms: representations of the Holy Cross, reproduction of prints held in pockets. I have never seen such figures. The peculiar effects of a lightning discharge, even outside its direct course can generally be traced to the enormous expansion of air due to sudden heating in the thread-like path of the flash, and to electric induction — in other words to the disturbance of electric equilibrium in all neighboring objects. While studying the effects of sparks seven feet in length, I perceived sparks between points at considerable distances from the exciting spark: assistants standing close to brick walls were pricked, and combustible material ignited. There were also dendritic figures — like branches of trees — formed on glass and other material: these were inductive effects due to the high so-called static charge preceding the flash. Some have attributed such markings to the X-rays; but I have failed to find any X-ray phenomena in electric discharges in air. Indeed we shall see when radioactivity is discussed that X-rays are produced only in air or gas of extreme tenuity — a state of vacuum as nearly as it can be obtained. Such a state of vacuum does not exist in air when submitted to lightning discharges.

CHAPTER V

CAUSES OF LIGHTNING

SINCE the time of Franklin our realization of the immense display of energy in lightning flashes has greatly increased: no one today would venture to repeat his epoch-making experiment; for we know that lightning manifests in less than a hundred thousandth of a second more than the most powerful dynamo can produce at the instant of its greatest activity. At present we are entirely at a loss to account for the presence of electricity in the sky — the electronic theory bids fair to increase our knowledge of the conditions which may produce thunder storms. There seems to be no doubt that even in fair weather and during cloudless skies there is always a state of comparatively high tensión in the earth's atmosphere. Professor McAdie, Director of the Blue Hill Observatory, flew a kite near the physical laboratory of Harvard University and obtained at even small elevations an electromotive force equal to that of five storage cells.

There are many theories to account for atmospheric electricity. The supposition has been made that it is caused by friction, either between clouds or between clouds and the surface of the earth: the production of electricity by scuffling over a carpet, the stroking of fur is a familiar fact. But how can friction arise between wet clouds and their passage over wet earth? Wind may be an agent, but wind does not always precede cumuli clouds charged with electricity. These clouds often rise like giants with slow ponderosity; during an apparent calm a concealed wind might act like the steam in Sir William Armstrong's hydroelectric machine, forcing vesicles of water against dry obstacles, but it is difficult to see how regions of dryness can exist in clouds, or in the surrounding air. The internal work of the clouds in producing electricity must apparently result from some molecular change in vapor: some resolution of electrons. Cannot evaporation or condensation be instrumental? I have made attempts to produce electricity by evaporation of water but have not succeeded.

It is related by observers in Australia that thunder storms often sweep over desert plains, and lightning flashes are seen but no rain falls. The same phenomenon is observed on the dry plains of America. Since there is little evaporation from such dry surfaces the electricity over such surfaces is apparently not caused by evaporation, unless the evaporation takes place in regions remote from deserts. Generally speaking, however, thunder storms are local phenomena. Professor Douglas has investigated the effect of dust storms of South Africa in contributing an electrical charge to the atmosphere, and finds that nearly all finely divided materials when blown into clouds of dust give rise to electrical charges on the dust and on the air. The nature of these charges depends on that of the dust. Strongly basic substances give negative charges; strongly acidic give positive. In the case of salts the charge depends upon the relative strength of acidic and basic ions. Similarly constituted bodies give similar charges. During normal fine weather in South Africa the atmosphere is usually positive; at an elevation of 4500 feet the charge seldom exceeds 200 volts (the volt is the unit of electromotive force; an ordinary dry cell such as is used in automobiles to provide ignition sparks has an electromotive force or voltage less than two volts). During dust storms the sign often changes, and one may have 500 volts per metre (39.27 inches.) A "dustdevil" often carries columns of sand to heights of 200 to 300 feet, and produces effects more than two miles away, generally reversing the positive charges of the air: the electrification of the dust storms is invariably negative. In England the dust from automobiles has the effect of increasing the positive charge of the air; the roads are for the most part calcareous, while in Africa they are usually siliceous. Professor Douglas believes that the negative charges produced by dust storms reside in the air itself and not in the dust particles. Dust may be contributory over deserts and dry areas; but it seems to play a small part in districts covered by forests: thunder storms sometimes end a long period of rain, when dust is laid.[1]

The excitation of electricity by friction was the feeble forerunner of the method of the dynamo. Franklin, in all his researches, produced electricity by means of the friction of a leather pad, covered with an amalgam of mercury, against a glass disk which was revolved by hand. Electricity can be generated by rubbing together almost any two dry insulators, such as two sheets of paper, slippers on dry carpets, or two silk garments. Sparks so excited have very large electromotive force but exceedingly small current strength. Early experimenters collected many facts in regard to the kind of electricity generated by the friction of various substances — whether positive or negative. Franklin used the terms positive and negative to denote excess or deficit of an electrical charge. The earth was supposed to be a sink of electricity, in other words to have a deficit. The electrical states of all bodies were compared with the state of the earth. Franklin's conception, expressed in modern language, is thus stated — there is a difference of potential between positively electrified bodies and the earth, or negatively electrified bodies. Difference of potential means a capacity for doing work or producing a spark. Textbooks on electricity contain lists of substances which exhibit either positive or negative charges when rubbed together. Most substances can be made either positive or negative by properly choosing the substance by means of which the rubbing is done; thus glass is positive when rubbed by silk, and negative when rubbed by fur. In frictional electricity we find one of the greatest problems in regard to the constitution of matter. The electron has evidently a comparatively free motion on or through metals, but it is impeded or imbedded in the surface of non-conductors or insulators, and remains there as a constituent of an electrical charge.

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[1] *Phil. Mag.*, 1912, p. 494. *Phil. Mag.*, 1913, p. 854.

The belief in friction as a cause of thunder storms has now given place to one of disruption of molecules of water, which is due to Dr. Simpson. He concludes from experiments undertaken at the meteorological station of the British government at Simla, India, in 1907–08,[1] that when pure water is broken up from large drops to small drops in the air, a separation of electricity takes place. This separation may be caused by strong ascending or descending currents of air in thunder clouds. One finds an analogy to this theory in Langley's conception of internal work of the wind and clouds to account for the soaring of birds.

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[1] *Phil. Trans. R. S.*, Series A, vol. 209, pp. 379–413.

The manifestations of lightning in thunder storms near the surface of the earth are not extremely varied: we have the brilliant forked flash and heat lightning, which is the reflection of distant flashes below the horizon — similar to that of the sparks from trolley lines on cloudy skies at night. The forked or zigzag character of lightning disappears at high altitudes: in air of only two or three inches of pressure the discharges become perfectly straight or lose entirely their line character. John Bowdoin had a clear conception of this changed appearance of electrical discharges in the upper atmosphere and thus expresses it in a letter to Franklin, Boston, December, 1751.(1

"The electrical fire, passing through the air, has the same crooked direction as lightning.* This appearance I endeavor to account for thus. Air is an electric *per se;* therefore there must be a mutual repulsion between air and the electrical fire. A column or cylinder of air intervenes between that part of the body from which the spark is drawn and that of the body it aims at. The spark acts upon this column and is acted upon by it, more strongly than any other neighboring portion of air. The column being thus acted upon becomes more dense and, being more dense, repels the spark more strongly; its repellency being in proportion to its density. Having acquired by being condensed a degree of repellency greater than is natural it turns the spark out of its straight course; the neighboring air, which must be less dense, and therefore has a smaller degree of repellency

having the diameter of its base equal to the diameter of the electrical spark.

1. Sparks Life of Franklin Vol. V p 264.

2 * This is most Easily observed in large strong sparks, taken at some inches apart

gives it a more ready passage. . . . The electric spark, if the foregoing is true, will pass through a vacuum in a straight line." The governor suggests that his thought could be tested by means of an air pump. His conclusion is correct, if we understand by his vacuum a pressure of two or three inches of mercury; but when the pressure of air or of gas is further diminished the straight line discharge entirely disappears and we have a glow which is that of the aurora. The manifestations of electricity in air and gases at pressure where the line appearances of sparks disappear and the aurora effects appear have almost completely diverted the attention of physicists from the observation of lightning. This field was beyond the observation of Franklin. It is now the most fruitful field of inquiry and affords the most practical results. In his time there was not a glass blower in the world who was competent to make an electric light bulb, or a tube to contain highly exhausted air provided with metallic terminals to lead electric discharges; moreover a suitable degree of exhaustion in such glass vessels could not be obtained by the air pumps of Franklin's time.

We have gone, so to speak, beyond the phenomena which attracted so strongly his attention; and we find in silent discharges the most fertile field of inquiry both in regard to theory and practice. Physicists are realizing this more and more; and in the field of practical electricity we have the electric light bulb and its congener, the audion, which has supplanted the electric spark in wireless telegraphy. The regions of the upper atmosphere supply the conditions for silent discharges such as we can provide in glass tubes filled with air or gas at low pressure.

The stupendous effect of electricity in motion may be said to have been concealed in Franklin's experiments. We are reminded of the Arabian Night tale of the fisherman and the genie. Within a bottle — the Leyden jar — were confined the elements of a most powerful agency. An imaginative writer could also picture in the loss of Franklin's electrical charges — their leaking away, another mysterious agency which is now recognized as radioactivity — a subject which is intimately connected with the electron theory.

The Leyden jar, or bottle which Franklin used in order to accumulate electrical charges was simply a glass jar, coated on the inside and outside with tin-foil, the inside and outside tin-foil not being in connection with each other. The two layers of tin foil were suitably connected to the terminals of his electrical machine, and one layer — we will say the inner — was charged positively, while the outer was charged negatively. The Franklin plate was a glass plate coated on both sides by independent layers of tinfoil — it can be imagined as a Leyden jar slit, and rolled out as a plate. These accumulators of electrical charges played a great part in Franklin's investigations; and they have great importance in modern practical electricity. Franklin's imagination was greatly stirred by the power which could be confined in his bottles, and in a letter to Cadwallader Golden thus speaks of the unlimited nature of the electric force:

"I forget whether I wrote to you that I have melted brass pins and steel needles, inverted the poles of the magnetic needle, given a magnetism and polarity to bodies that had none, and fired gunpowder by the electric spark. I have five bottles that contain eight or nine gallons each, two of which are sufficient for those purposes; but I can charge and discharge them all together. There are no bounds (but what expense and labor give) to the force man may raise and use in the electrical way; for bottles may be added to bottles *ad infinitum*, and all discharged together as one, the force and effect proportioned to their number and size. The greatest known effects of common lightning may, I think, without much difficulty, be exceeded in this way, which a few years since could not have been believed, and even now may seem to many a little extravagant to suppose."

CHAPTER VI

A BAR TO FRANKLIN'S ADVANCE

FRANKLIN'S one fluid theory gives a reason for the occurrence of positive and negative charges; the negative is due to a deficit of electricity, the positive to a surplus. In the electron theory the detachment of the negative particle — the electron from an atom — constitutes the negative and positive state. Franklin, however, could not carry his theory very far, since in his time the relations of magnetism and electricity were entirely unsuspected except from a supposed action of the electric spark in reversing the poles of a magnet. Franklin in a letter to M. Dubourg, × due probably to a request of the latter for an opinion on this action, sums up all the knowledge of the time in regard to the relation of magnetism and electricity. I give the letter, at length, to show Franklin's lingering belief in subtle fluids, and his complete unconsciousness of a most potent relationship between electricity and magnetism. !

LONDON, 10 March, 1773.

"Sir:

As to the magnetism, which seems produced by electricity, my real opinion is, that these two powers of nature have no affinity with each other, and that the apparent production is purely accidental. The matter may be explained thus.

1. The earth is a great magnet.

2. There is a subtile fluid, called the magnetic fluid, attracted by all their parts which exists in all ferruginous bodies, ~~equally diffused~~ attracted and

× Sparks - The works of Franklin
Vol V. p.450

through their whole substance; at least where the equilibrium is not disturbed by a power superior to the attraction of the iron.

3. This natural quantity, of the magnetic fluid, which is contained in a given piece or iron, may be put in motion so as to be more rarified in one part and more condensed in another; but it cannot be withdrawn by any force that we are yet made acquainted with, so as to leave the whole in a negative state, at least relatively to its natural quality; neither can it be introduced so as to put the iron into a positive state or render it plus. In this respect, therefore, magnetism differs from electricity.

rarefied

4. A piece of soft iron allows the magnetic fluid which it contains to be put in force by a moderate force; so that being placed in line with the magnetic pole of the earth, it immediately acquires the property of a magnet, its magnetic fluid being drawn or forced from one extremity to the other; and this effect continues as long as it remains in the same position, one of its extremities becoming positively magnetized and the other negatively. This temporary magnetism ceases as soon as the iron is turned east and west. The fluid immediately diffuses itself equally through the whole iron, as in its natural state.

5. The magnetic fluid in hard iron or steel is put in motion with more difficulty, requiring a force greater than that of the earth to excite it and, when it has once been forced from one extremity of the steel to the other, it is not easy for it to return; and thus a bar of steel is converted into a permanent magnet.

6. A great heat, by expanding the substance of this steel, and increasing the distance between its particles,

affords a passage to the magnetic fluid, which is thus again restored to its proper equilibrium, the bar appearing no longer to possess magnetic virtue.

7. A bar of steel which is not magnetic, being placed in the same position relatively to the pole of the earth which the magnetic needle assumes, and in this position being heated and suddenly cooled, becomes a permanent magnet. The reason is that while the bar was hot, the magnetic fluid which is naturally contained was easily forced from one extremity to the other by the magnetic virtue of the earth; and that the hardness and condensation produced by the sudden cooling of the bar retained it in this state without permitting it to resume its original situation.

8. The violent vibrations of the particles of a steel bar, when forcibly struck in the same position, separate the particles in such a manner during their vibration that they permit a portion of the magnetic fluid to pass, influenced by the natural magnetism of the earth, and it is afterwards so forcibly retained by the reapproach of the particles when the vibration ceases that the bar becomes a permanent magnet.

9. An electric shock passing through a magnet in a like position, and dilating it for an instant, renders it for the same reason, a permanent magnet; that is, not by imparting magnetism to it, but by allowing its proper magnetic fluid to put itself in motion.

10. Thus there is not in reality more magnetism in a given piece of steel after it is become magnetic, than existed in it before. The natural quantity is only displaced or repelled. Hence it follows that a strong apparatus of magnets may charge millions of bars of steel, without communicating to them any part of its proper

magnetism, only putting in motion the magnetism which already existed in these bars."

It will be observed how strongly the idea of fluids was in Franklin's mind both in regard to electricity and magnetism: the motions of the electron have taken their place today. Fluid theories have disappeared: such theories prevailed one hundred and thirty years ago, together with the phlogiston theory which maintained that all substances capable of burning contained a substance — phlogiston — which was the basis of combustion, and the caloric theory which asserted that an imponderable medium exhibited or conveyed heat. Count Rumford during Franklin's life, hoped to see phlogiston and caloric buried together in the same grave: he might have foreseen a burial of kindred fluid theories. Is the theory of an ether, which has long prevailed, destined also for the cemetery? Yes!

Electric sparks similar to lightning, in ordinary air, jump to a magnet presented to them: the electrostatic attraction is far stronger than any magnetic effect. When, however, an electric discharge passes through rarified air it can be greatly affected by magnetic influences. When the pressure of such air approaches that of the atmosphere where the aurora takes place the discharges are very sensitive to magnetic influences. The streamers of the northern lights are grouped about the pole of the earth; they move in sympathy with what are called magnetic storms — probably produced by the sun. Indeed the relation of magnetism to electricity is the most significant one in the history of electrical science, and has led to all the theoretical and practical developments of electricity of modern times.

Franklin could not have discovered the connections between magnetism and electricity without covered wire and a battery. The discoveries of Galvani and Volta came long after the working period of Franklin's life had ceased. With these discoveries the attention of philosophers was diverted largely from static electricity, which had entirely absorbed Franklin's attention, to the relations of magnetism to electricity. The want of covered wire — insulated wire — would have been one of the barriers to his making further advances in his favorite subject. The use of electricity could not have been one of the lost arts; for there is every evidence that the ancients did not have insulated wire. It is not so long ago that Joseph Henry had to use his wife's cast-off skirts to wrap about his copper wire, in constructing electromagnets. The need of suitable means of insulation was the first bar to the advance of our knowledge of electricity; and today is the chief obstacle to our utilization of great electrical energy at our command, in the transmission of power over great distances.

Franklin's attitude of mind in regard to magnetism was not one even of doubt in regard to a relation between it and electricity: he was apparently certain of a condition of no relation; possibly he might have agreed with the words of Sir Francis Bacon, contained in the latter's essay on the errors of learning, which are as follows: "Another error that hath some connection with this letter is that men have used to infect their meditations, opinions, and doctrines, with some conceits which they have most admired or some sciences which they have most applied, and giving all things else a tincture, according to them, utterly untrue and improper. So hath Plato intermingled his philosophy with theology, and Aristotle with logic; and the second school of Plato, Procius and the rest with mathematics; for these were the arts which had a kind of primogeniture with them severally. So have the alchemists made a philosophy out of a few experiments of the furnace; and Gilbert, our countryman, hath made a philosophy out of the observation of a loadstone."

The eminently practical mind of Franklin saw no possibility of utilizing electrical energy. He did, however, express the opinion that there was no limit to the quantity of electricity he could accumulate if he could increase indefinitely the extent of surface of his Leyden jars, or plates. He mentions having killed turkeys by the electric spark. In his time it was a frequent source of amusement to shock people by the mysterious fluid: popular interest in the subject of electricity was confined to the manifestations of lightning and to the amusing convulsions produced in human beings by feeble earthly representations of it: even more than thirty years after the death of Franklin this limited interest in the subject which absorbed so greatly his attention prevailed. In 1833, at a meeting of the British Association for the Advancement of Science, Armstrong showed a new electrical machine for producing strong sparks, and *Chambers Journal* of that year, prefacing its account of the meeting of the Association with the words: "Our readers are aware that we regard that body and its proceedings in a favourable light," thus continues with a recital of the effects of the Armstrong machine. "At one time we observed a long loop of people with joined hands, extending through the multitude in the senate house somewhat like a party standing up for country dance; several philosophers were of the number. When the engine was put in motion, the whole of these persons might have been seen in a kind of dance at one moment, from the effects of the electricity. Two minutes after Mr. Faraday was on the platform expounding the nature of the agent that had excited them all so much, in language that introduced awe and deep feeling where recently nothing but merriment had been." Faraday seemed to have appeared like a prophet of old with a prophecy of the coming of the dynamo. Long before persons had amused themselves with electric sparks they had found entertainment in the attracting power of the loadstone. Doubtless some itinerant performer in the time of the Caesars had puzzled the crowd by causing movements of loadstones on boards beneath which were moved other loadstones; just as we see today iron dolls pirouetting on surfaces in shop windows, put in action by the movements of concealed magnets — permanent or electromagnetic.

CHAPTER VII

A NEW METHOD OF STUDYING LIGHTNING

THE study of lightning has been pursued mainly from statistics gathered by meteorologists and from photographs of discharges. These photographs are very easy to obtain; for it is only necessary to point a camera to the sky at night and expose a plate or film: the chances are good that a wandering discharge will be caught. The intensity of its light is generally very great: a thousand-candle power searchlight waving from a source a mile away makes no impression on the retina when the eye is closed; but a lightning discharge at this distance will often produce a sensation of light in closed eyes. The camera generally records a zigzag line, sometimes a succession of discharges, called chain lightning — the first discharge apparently opens up an avenue which succeeding discharges closely follow. In scientific language it is said that the air is ionised by the first discharge and made a good conductor. Many pseudo-effects have resulted from accidental jarring or other movement of the camera; thus we have ghosts and ribbon discharges. The numerous photographs reveal little that cannot be discerned by the eye alone. They do not show that a spark discharge consists of a preliminary bolt which is called the pilot discharge, generally followed by oscillatory discharges which follow each other at intervals of one hundred thousandths of a second, more or less. In certain cases where the discharge encounters great resistance these oscillations are suppressed, and we have what is termed a unidirectional discharge. It is still an open question whether lightning is oscillatory. I believe from the study of powerful discharges in the laboratory that it is. The oscillations of these discharges could always be suppressed by interposing in their circuit very large resistances such as long columns of distilled water. It may be that lightning occasionally finds such great resistances in the clouds. Such resistance greatly diminishes the strength of the discharge. The photographs of lightning show one effect which is not seen in eye observations — the phenomenon of dark lightning — this is a chemical reversal of a light-struck photographic plate.

It is rare that sparks produced in a laboratory, which seem to perfectly simulate lightning, do not oscillate. It appears as if this to and fro action is characteristic of almost all electrical discharges. The study of their oscillations has become of great importance in electrical science. It has led to wireless telegraphy. Sir Oliver Lodge, in his treatise entitled *Modern Views of Electricity*, gives an interesting account of the oscillatory discharges of the Leyden jars, or Franklin plates, which Benjamin Franklin employed in his investigations without knowing that there was an action in them which was destined to revolutionize the transmission of human intelligence. Lodge's book was published thirty years ago and contained no hint of the practical use of electrical oscillations. There is one remark in his discussion of oscillations which bears upon the subject of the damage often produced by lightning. He mentions the double burr which occurs on the two surfaces of cardboard, when a spark perforates the cardboard, as an example of electrical oscillation. In his opinion it is made by a to and fro oscillation. I arranged a circuit of great resistance which, I proved, suppressed all oscillations and left only the pilot or bolt discharge. Nevertheless the burr still was produced. It is not therefore the result of oscillations but it is due to an explosion, probably that which results from air enclosed in the cardboard — air which is suddenly expanded by the spark. The shattering of tree trunks by lightning, the dispersion of powder without ignition are examples of similar explosion.

The study of lightning has been conducted with more success in laboratories than by observations of its phenomena in the skies. It is true that in a laboratory we must rely upon the analogy between comparatively feeble sparks and immensely great ones. The chief methods employed in laboratory researches is that of the revolving mirror; and the underlying principle is the same as that of the moving picture. The impression of a moving object remains on the eye for one-sixteenth of a second. A photographic plate or film can be moved at such a rate that pictures taken at intervals of one-sixteenth of a second can separate movements into their constituent parts. The motions or oscillations of an electric spark succeed each other on a fairly long circuit by hundred thousandth's of a second. In order to separate what seems a line discharge into a bead-like one, it is necessary to move the photographic plate or film with great speed; but it is not practicable to do this along a horizontal line. It can be done, however, by throwing the image of the spark by a rapidly-revolving mirror on a stationary photographic plate. If the image is thrown around the circumference of a circle ten feet in diameter — the receiving photographic film being on this circumference — separated images of the oscillations of the spark can be obtained. A comparatively slow turning of a mirror can throw the image of the sun over a great arc. It is not practicable to wrap a photographic film around the circumference of a revolving circle; the position of the images on the film could not be arranged or foreseen. Many attempts have been made by scientific men to set off the spark at the moment when the revolving mirror should be in such a position that it would receive its image but without result. It has been reserved for Professor Sawtelle of the Physical Laboratory of Harvard University to solve the problem; and his method will prepare our minds for a subsequent chapter on photo-electricity. He employed the fact that ultra-violet light thrown on the terminals between which the spark jumps can set off the spark. The light serves as a trigger. He, therefore, arranged two mirrors on the same revolving shaft, one mirror threw ultra-violet light on the spark terminals; the other reflected the images of the oscillations of the spark on any desired position of the photographic recipient.

The study of electric oscillations has shown how to tune electrical circuits in order that widely separated ones, such as the aerials of wireless telegraphy, may be in harmony — the oscillations of the sending spark in tune with the excited oscillations at the receiving end; if they are not in tune there would be interferences which are analogous to beats in music. It may be asked why should not the still mooted question—whether lightning oscillates — be solved by examining the oscillations on a telegraph circuit, or a wireless aerial, caused by a lightning discharge. If beats on interferences are observed it would be a proof that the oscillations of lightning interfered with those which are natural to the earth lines; for even a non-oscillatory discharge of lightning — a pilot discharge — can arouse the fundamental note of earth circuits. No such observations have been made in regard to lightning. If beats are observed — irregularities in photographic records of sparks on land lines, caused by the inductive effect of lightning — it would be proved that lightning oscillates.

We cannot employ the revolving mirror method of inquiry in the direct study of lightning in the heavens, for we do not know where the flash will occur, or the exact time of its appearance.

CHAPTER VIII

THE BEGINNING OF THE ART OF WIRELESS TELEGRAPHY

IT is interesting to note that the discovery of the oscillatory nature of the electric spark, which is the basis of wireless telegraphy, was due to an American, Joseph Henry. Sir Oliver Lodge in his *Modern Views of Electricity* gives a very appreciative account of Henry's investigation. “This great man (Henry) arrived at a conviction that the Leyden jar discharge is oscillatory by studying the magnetization of steel needles by Leyden jar discharges, first observed by Savary in 1824. Fine needles, when taken out of the magnetizing helices, were found to be not always magnetized in the right direction, and the subject is referred to in German books as Anomalous Magnetization.” It is not the magnetism which is anomalous but the currents which have no simple direction, and we find in a memoir published by Henry in 1842 the following words:—

“This anomaly, which has remained so long unexplained and which at first sight appears at variance with all our theoretical ideas of the connection of electricity and magnetism, was, after considerable study, satisfactorily referred to by the author [Henry] to an action of the Leyden jar which had never before been recognized. The discharge, whatever may be its nature, is not correctly represented (employing for simplicity the theory of Franklin) by the simple transfer of an imponderable fluid from one side of the jar to the other;

the phenomenon requires us to admit the existence of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is obtained; all the forces are shown to be in accordance with this hypothesis, and a ready explanation is afforded by it of a number of phenomena which are to be found in the older works on electricity which have until this time remained unexplained." Lodge, in quoting this from Henry's memoir, says, "The facts studied by Henry do, in my opinion, support his conclusion and, if I am right in this, it follows that he is the original discoverer of the oscillatory character of a spark, although he does not attempt to state its theory."

Henry was on the verge of the discovery of wireless telegraphy. How often it happens in physical science that the investigation of what seems anomalous leads to great discoveries. Pasteur was led to his important work in ferments by the observation of minute differences in little crystals which previous observers had dismissed as slight irregularities. Lord Rayleigh investigated small constant error in the determination of the atomic weight of gases, and discovered the gas argon, a discovery which led the way to the discovery of a series of other gases. Argon promises to be of practical value in electric lighting. Bulbs filled with it retard the combustion of electric light carbons. It is said that now great electric industries find it profitable to repeat old experiments recorded in scientific literature as unsuccessful, or as giving anomalous results. The study of the leakage of electric charges which was so troublesome and baffling to Franklin might perhaps have led to the discovery of the great modern subject of radioactivity.

The study of the spark leads one into the heart of the mystery of electricity. Even before wireless telegraphy was discovered the greatest authorities in physics believed that this study would lead to important discoveries. It is now, I have said, been shown how to tune electrical circuits in order to transmit human intelligence. This tuning can be illustrated by arranging two circuits of copper wire — in the form of hoops — parallel to each other, each with small breaks or spark gaps. When an electrical disturbance sufficient to generate a spark is sent through one of these circuits, a spark will be formed in the neighboring independent circuit at its gap. The oscillations of this spark will depend upon those in the generating circuit, and also upon the form and dimensions of the neighboring circuit. The two circuits can be so arranged that the oscillations in one are exactly similar to those in the other. They are then said to be electrically tuned. If they are not electrically tuned interferences will arise which are analogous to beats in sound and which might annul the transmission of effective oscillations from one circuit to another.

In the frontispiece of a treatise entitled *What is Electricity?* [1] a photograph is shown of the effect of an exciting circuit upon neighboring circuits: a non-oscillatory discharge in one circuit can produce an oscillatory discharge in an independent circuit; the oscillations in the latter circuit depend upon its form and dimensions. Thus a discharge of lightning, granting that it is not oscillatory, could excite oscillations in telephone or telegraphic circuits. It may be thus seen how practically important has been the study of the spark by the revolving mirror. This study has accomplished its work. We shall see that the electric spark in wireless telegraphy has now been almost superseded by methods of exciting movements of electrons sympathetic with the waves of sound produced by the human voice.

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[1] D. Appleton & Co., N. Y., 1896.

A vibrating tuning fork can excite another if the two forks have the same pitch. The story is told of a violinist breaking down a bridge by sounding the note of the bridge. This may be too forcible an illustration of the theory of resonance; but it is correct in principle. An electrical circuit excites a current in another independent circuit more efficiently when the neighboring circuit is electrically tuned to the first. The principle of tuning has universal application in wireless telegraphy; so much so that receiving stations can select electrical waves and refuse others to which the apparatus is not electrically tuned. Every electrical circuit has its own period of oscillation; and when a current in one circuit excites by induction a current in another there will exist a forced vibration due to the exciting circuit and another vibration peculiar to the neighboring circuit. In order that the forced vibration and the natural vibration should not interfere with each other, the two electric circuits should be put in step or electrically tuned to each other. The study of the electric spark by the revolving mirror has shown the necessity of this tuning, especially in the case of wireless telegraphy. Thus, what at first sight seemed only an aid to theory has become the greatest help in founding a new art — that of transmitting intelligence without the aid of wires.

Alexander Graham Bell, the inventor of the telephone, began his electrical career by endeavoring to perfect a method of sending many messages over a wire simultaneously which depended upon the principle of resonance.

The vibrations of different tuning forks, actuated by electromagnets, were transmitted as electrical currents and were selected at the receiving end of the circuit by tuning forks of the proper pitch: thus the vibrations of a C fork, or those of F, or G transmitted together would set in vibration at the receiving end, a C resonator, an F or a G. All depended upon the fundamental acoustical fact that the sound of any note can awaken the same note on a properly tuned receiver. The ear can pick out the notes of a singing bird from the accompanying sound of a drum. The air conveys vibrations which the ear selects and puts in its proper auditory chamber. In the same way multitudes of electrical vibrations can be conveyed on an electrical circuit of such high rate of oscillation or frequency that the ear listening, for instance, on a telephone cannot detect the frequency — the human ear is deaf to frequencies above forty thousand a second. Yet a proper arrangement of the electrical condensers — the Leyden jars, or Franklin plates — together with what are called induction coils of wire can transmit a multitude of accompanying vibrations, which can be selected at the receiving end of the circuit. Thus many messages can be sent over a wire without disturbing each other.

The method of the rapidly revolving mirror forcibly showed the importance of electric tuning and illustrated electrical resonance. It has now served its purpose, as I have said, and has been replaced by a hot wire, which under the influence of electromotive force throws off electrons in the audions or receivers now so generally used in wireless telegraphy. The aid of mathematical and laboratory investigations is well illustrated in the advances of electricity, and in no department of this subject better than in that of wireless telegraphy. The practical electrician might in time have seized upon the principle of electric tuning without the aid of theory; but it would have been at the expense of great labor, often of misdirected effort and loss of time. Would he have been ready for the great war? In this war wireless telegraphy played a most opportune part. During the last year of the struggle it had become possible by means of electrical tuning to locate, with great precision, submarines; bearings were taken from different points, and their intersection revealed the position of the submarine. By the use of the wave theory of electricity the professors of physics, who enlisted to aid the American government by their knowledge, succeeded in greatly perfecting the means of under-water communication. They showed the possibility of using, efficiently, several transmitters in tandem, so as to increase the effect of only one. During the last year of the great war the under-water hearing devices, in which electricity played a great part, had become so efficient that the enemy's submarines, desirous of escaping observation and pursuit, were diverted from their work of destruction.

Franklin's proof that a lightning discharge is identical in character with an electric spark leads one to attribute to it all the manifestations of sparks produced in a laboratory. In general, these latter sparks are oscillatory: they cease to be so when they arise in circuits of great resistance — circuits including distilled water. Electric sparks arising in such circuits are greatly reduced in length. The resistance of atmospheric air to lightning discharges is very small. This conclusion is proved by the analysis of sparks by the revolving mirror. I arranged a circuit which included two spark gaps: a spark in one of these gaps was analyzed by the revolving mirror, and its oscillations noted; varying resistances of copper wire were then introduced in place of the second spark which was not analyzed. In this manner the equivalent resistance of the second spark was found by noting the number of oscillations of the observed spark: these changed with the resistance of the circuit. It was found that the resistance of a spark six or seven feet in length was no more than one of an inch in length. The resistance, therefore, of a discharge of some hundreds of feet is no more than that of a spark one inch in length. I repeat that air opposes a very small resistance to the passage of lightning — in technical language not more than two ohms, a resistance offered by about 300 feet of copper wire, one-sixteenth of an inch in diameter. This small resistance of sparks is taken advantage of in wireless telegraphy: the minute spark at the receiving station in the original Marconi system allowed the use of a strong relay current which passed through the minute spark and which detected the wireless signals.

CHAPTER IX

ELECTRIC WAVES

THE revolving mirror's analysis of electric oscillations has corroborated the conclusions of mathematical theory which led to the belief that if electric oscillations were sufficiently rapid — as rapid as those of the waves of light — they would leave the surface of the conducting wire: this wire would only serve a directing purpose. Wireless telegraphy dispenses even with a directing wire, and the oscillating messages — so to speak — travel with the actual velocity of light. This mathematical conclusion was proved to be true by experiments with a revolving mirror conducted by Professor Duane and myself.[1] A circuit was arranged of such electrical dimensions that a spark produced in it was calculated to have oscillations of the period of light alternations. The extremely minute photographic records of the oscillations were measured and their period was found to be that of light. General Squier of the United States Army has based upon this fact of the merely directing effect of a circuit upon very rapid electric alternations a method of transmitting many messages to and fro upon the same wire.

The method of the revolving mirror which reveals the constitution of the electric spark has greatly aided, I have said, the development of wireless telegraphy; and has shown that electrodynamic waves used in this system of communicating intelligence travel with the velocity of light; that they are in fact light waves of great length, and we are led to the conclusion of Clerk Maxwell that light and electricity differ only in length of waves. A rainbow is thus really an electrical phenomena.

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[1] Fleming, *Electric Wave Telegraphy*, p. 270. Longmans, Green & Co.

At first sight lightning and the rainbow seem entirely unrelated phenomena. The theory that all light is electrical in nature, however, connects these manifestations in a very intimate way with the electron theory. In order to grasp this connection let us consider the spectrum of light, which is shown in such a resplendent manner by the rainbow. The colors of this spectrum run from red to violet, and these colors merge into each other without apparent breaks or lines, either bright or dark. Apparently the same spectrum is given by a prism which refracts the light of a candle. In these two spectra we have what the artists call the primary colors, red, yellow, and blue. The physicists, however, call the primary colors red, green, and violet. Red and green of the spectrum of sunlight, when combined, produce yellow; green and violet produce blue. The spectrum of the rainbow seems on cursory observation to be the only spectrum which has not dark lines: but a little reflection tells us that since the rays of this spectrum come from the sun, and since the spectrum of the sun is crowded with dark lines these lines must exist in the rainbow spectrum. The spectrum of lightning differs from that of the rainbow in showing a multitude of bright lines in the region of the red, yellow, blue and violet. These lines are due to the gases of the atmosphere which are highly heated by the lightning. The study of the spectra of the electric spark is of great importance in our endeavor to penetrate the secrets of its mechanism; and the method of Professor Sawtelle, Chapter 7, promises to be of great aid in this work.

The lines in the spectrum of lightning, I have said, are bright lines; they in general coincide with dark lines in the spectrum of the sun. The dark lines of the solar spectrum are due to the absorption of layers of gases or vapors of incandescent metals of the bright lines of these substances. In scientific language we say that when a beam of light is transmitted through a vapor or gas the wave trains of this beam are absorbed by colder layers of the same vapor or gas. By observing the coincidence of dark lines in the sun's spectrum with bright lines of a gas or incandescent vapor of a metal we discover the presence of gases or vapors of metals in the sun. This is a short statement of the great subject of spectrum analysis, which has now become a branch of electromagnetism.

Since all energy is now considered electromagnetic, it is sometimes asked by students, is there any electromagnetic spectrum, and, if there is, what is its character? The answer is, the visible light spectrum is really electromagnetic; in the invisible ultra-violet we have electromagnetic effects. Also in the region beyond the visible red rays there are invisible electromagnetic phenomena. The entire spectrum is electromagnetic. The shortest wave length that has been measured is that of the X-rays in the ultra-violet; the longest electromagnetic waves — the waves that are employed in wireless telegraphy — are far beyond the limits of the visible red waves.

The phenomena of electricity fifty years ago were considered apart from those of sound: the electric light, considered then only as an indivisible carbon light, seemed to be the only connection between light and electricity: the heat manifestations of the electric current were referred back to molecular motions in the voltaic battery, for the dynamo was invented only after Faraday had discovered the laws of electromagnetic induction. Now the main facts of electricity are as clearly expository of the conservation of energy as Tyndall showed that all heat phenomena were. The relations of acoustics to electricity are not so much those of energy as of analogies of resonance. The vibrations of the sound waves are in the direction of the propagation of the waves, while in light, heat and electricity the vibrations are at right angles with the direction of the waves, — that is transverse. The phenomena of interference of waves and resonance, however, is common both to sound and electricity; and this resonance or unison is the most important principle in telephony both on material circuits and in wireless telegraphy.

The main, indisputable fact in physical science is this, we are dealing in sound, light, heat, and electricity with wave motion: successive trains of waves can either aid each other or destroy each other. One is conscious of this in observing the course of ripples on the surface of water. Every now and then the waves unite and a surge results. When the waves interfere the water can remain undisturbed. In music when the sound waves interfere we have disagreeable beats or the wolf phenomenon due to periodical heaping up, or obliteration of waves by their interferences. In order that trains of waves following the same path should not interfere with each other it is necessary that they should be in step.

Have we not exhausted the subject of lightning? Is it not left where Franklin left it, beyond our means of study in the skies? for we cannot establish stations of observations on the clouds. There does not seem much hope from balloons and aeroplanes: they are especially liable to be struck by lightning, and lightning rods would be no protection for them. But we have harnessed, so to speak, lightning, and have realized an old dream — by means of the dynamo. We have metaphorically brought lightning to earth. There are some, however, who dream of a more direct translation: the dream of actually tapping the source of electricity in the heavens. The energy manifested in a lightning discharge is certainly very great, for its electromotive force is often many millions of volts. I have described the result of a research with a revolving mirror which showed that the electrical resistance of air to the passage of a spark is very small. Since the electrical current is the electromotive force divided by the resistance of its path, we have in the case of lightning an enormous exhibition of energy: it lasts, however, but a very short interval of time — less than one hundred thousandth of a second (Shakespeare says "Lightning doth cease to be, ere one can say it lightens") — and there is no possibility of keeping up a constant succession of lightning discharges. But since there is a constant electrical charge in the upper atmosphere, a positive charge, while the earth is always negatively charged, is it not possible that some means will be devised to utilize this difference in electrical level? There seems to be far more promise in utilizing the energy of tidal motion: in both attempts it is suggested that the storage battery might play a part.

CHAPTER X

STUDY OF LIGHTNING IN A LABORATORY

SINCE we have apparently reached a limit in our study of lightning in the sky — for the photographs of its manifestations in the clouds yield no new facts, and meteorological statistics are of chief interest to the weather bureau — these statistics give no information of the mechanics, so to speak, of the lightning discharge. It seemed to me of interest to study powerful electric discharges in a laboratory by an extension of Franklin's method of condensers or Franklin plates — discharges which closely simulate lightning discharges. Professor Elihu Thomson and Mr. Tesla have obtained and studied most powerful electric discharges by means of dynamos and induction coils; these discharges closely resemble lightning in their zigzag paths; but the discharges from Franklin plates in tandem seem more nearly allied to lightning in their method of origin than the discharges caused by dynamos and induction apparatus. The discharges of condensers of Franklin plates in tandem, or one condenser after another, was made possible by means of the storage battery of the Jefferson Physical Laboratory which consisted of 20,000 cells. The discharges of the condensers in series awakens the interesting question how such discharges are formed in the clouds. One large condenser shortens an electric discharge, the surfaces of the clouds do not act therefore as one large condenser.

The storage battery I employed was in principle that of Plante, who discovered that two lead plates immersed in dilute sulphuric acid could store up a large portion of the electric current which traversed the liquid; and the current was used to polarise, so to speak, the plates. The polarisation current, after the charging current is removed, results from the return of the peroxide of lead formed by the charging current to the original neutral state. Plante charged a large number of lead plates — eight hundred — by two or three batteries, or voltaic cells, and described the effects he obtained in a brochure entitled *Researches in Electricity*. His experiments with this storage battery constituted the first important study of lightning in a laboratory. Before his time no experimenter had been able to study the effect of strong electric currents combined with large electromotive forces. Among other results he believed that he imitated what is popularly called ball lightning — that bomb-like explosion which many persons state that they have noted in thunder storms. There was a promise, therefore, of obtaining proof by means of a large storage battery of the existence of the phenomenon of ball lightning.

A detailed account of the installation of 20,000 storage cells in the Jefferson Physical Laboratory is contained in a memoir, published March 13, 1907, by the American Academy of Arts and Sciences. Each cell of the battery consisted of a test tube, such as is employed by chemists. It contained two strips of lead. These strips were separated from each other by sheets of kiln dried wood and immersed in dilute sulphuric acid. When fully charged by a dynamo current each cell gave an electromotive force of two volts. The entire battery thus afforded a force of forty thousand volts. When the terminals of the battery were two inches apart a thin spark passed from one terminal to the other, which was followed by a yellow-colored flaming discharge which could be drawn out to a length of thirty inches. This flaming discharge has no counterpart in lightning. In order to avoid danger it was well to keep one hand in a pocket. A faint glow was always seen at the negative terminal of the battery when the terminals were widely separated so that no spark passed. This leakage shows the difficulty of obtaining good insulation. Although the cells were placed on kiln-dried wood — an insulator which I found superior to glass or rubber plates — there was always leakage. One of the greatest problems in applied electricity is to find a better insulator than we now have. Even if the body of an insulator is a good insulator its surface becomes moist or is covered with conducting dust. One observes in travelling across the continent tiers of mushroom-like glass insulators on poles carrying long distance transmission lines of electricity. These successive insulators prevent to a certain degree the leakage of the currents.

I have mentioned the Leyden jar in reference to Henry's discovery of electrical oscillations. A more general name for the Leyden jar is that of condenser. The method of charging plate condensers by a storage battery is to connect the negative pole of the battery to one coated surface of the plate and the positive pole to the other surface. Such plate condensers can be discharged either after connecting all the negatively charged surfaces together, and the positively charged surfaces together, or connecting the condensers so to speak in tandem, that is, connecting the positively charged surface of a plate to the negatively charged plate of another plate and so on — just as if one were connecting chemical cells in series. In the first case — that of a large reservoir — we can obtain a quantity discharge; in the latter a high tension, or high electromotive discharge. In the tension discharge we have the sum of the individual charges of the plates.

I found that glass plates suitable for condensers could not be less than one-eighth of an inch in thickness to withstand the electrical pressure or electromotive force of a battery of 20,000 storage cells. When the quantity method of discharge was employed through a large resistance, such as a tube of water, the discharges followed each other at regular intervals — the battery serving as an electrical clock; its action was like that of the human heart: after each discharge there was a period of recuperation and then another discharge. The spark from the condenser of a large surface, such as that afforded by connecting all the surfaces of the individual condensers intended to be charged negatively, and all the surfaces of the plates to be charged positively, is what may be called a fat spark: it does not resemble a discharge in lightning; it is not zigzag; but is short and straight, whereas the length of the sparks obtained by connecting the condensers in series was over six feet, and closely resembled lightning discharges. A suitable mechanical arrangement enabled me to charge the condensers in multiple, so to speak, and then to discharge them in series.

Does this series discharge indicate that a similar one takes place in the clouds? It is an interesting problem to consider how individual charges in the heavens can unite to produce such a series discharge: a quantity discharge such as can be produced by a storage battery and the arrangement of one large condenser is not seen in a thunder storm. The noise of discharges six or seven feet long, in a laboratory, is hardly that of a pistol. The electromotive force, however, of these discharges caused sparks a hundred feet from the battery: these sparks could be drawn from the brick walls of the laboratory. A close examination of the photographs of the discharges disclosed the fact that at each fork or zigzag there was a diffuse discharge, similar to a brush discharge which is ordinarily seen at a terminal before a spark jumps. It seems probable that a similar phenomenon takes place at each fork of a lightning discharge. On passing the spark between a plate of glass on a sheet of paraffined paper, the paper was perforated at each forking of the discharge. Possibly these evidences of explosions along the entire path of forked discharges may be an element in the rolling of thunder: the sound caused by such explosions might reach the ear of a listener at successive intervals of time. It would seem as if a stream of projectiles — electrons — issuing in a mass from the negative terminal lose their energy in a diffuse, spreading brush. The discharge from the positive terminal does not manifest this phenomenon so strongly.

The electromotive force necessary to produce a spark six feet in length, in air, is approximately one million volts, and the voltage of discharges of lightning, often many hundreds of feet in length, may be conjectured. It would seem, from a study of photographs that I obtained in a laboratory, that their general appearance closely resembles those of lightning. At a distance from either spark terminal, the discharge is a zigzag line of light. Peculiarities, however, can be noted which are not seen in photographs of lightning. At the terminals there was a brush of light, more pronounced at the positive terminal than at the negative. An easy method of determining which was the positive and which the negative consisted in observing these differences. The persistent light at the negative terminal suggests an explanation of St Agnes' fire and the mysterious glows, or slow perambulating effects sometimes seen in electrical storms.

The phenomenon at the negative terminal is full of significance as we shall see when we enter upon the subject of radioactivity. We have spoken of Professor Sawtelle's use of the effect of ultra-violet light in producing the release of electrons at the negative terminal. The resistance of a lightning flash, I have said, must be very small. The air opposes during the discharge little obstacle to the passage of a great amount of energy in a small element of time. This energy is distributed through a minute path; for the actual cross-section of a discharge of lightning is minute. To obtain an idea of the diameter of this cross-section I passed long sparks through a fine needle hole in a plate of glass five feet square. The hole was pierced in a plug of paraffine which stopped a larger hole in the glass. The spark on each side of the needle hole appeared to the eye to be, at least, a tenth of an inch in diameter. One, therefore, realizes what a tremendous amount of energy is transmitted in a short interval of time through a narrow path in the sky. The expansion of air due to the heat developed in this path may explain by successive reflections of the sound of the explosion, from clouds and the earth, the rolling of thunder and also the shattering of tree trunks — if the discharge maintains its thin dimensions in passing through material obstacles.

There is one reported phenomenon of lightning which has never been photographed either in the heavens or in the laboratory — the so-called phenomenon of ball lightning. Planté believed that he had its representative in what he called perambulating sparks — slowly moving discharges over surfaces. Righi[1] by the use of large Leyden jars or condensers which he discharged through long columns of water, obtained globular effects which moved slowly through rarified air. I have repeated Rhigi's experiments and instead of charged condensers I passed the current from the large storage battery through long columns of water. Luminous masses of light emerged from the negative terminal in a tube of air rarified to the degree where line discharges were not formed, and proceeded very slowly to the positive terminal.

Righi

May there not be meteorological conditions which permit slowly moving electric discharges which are imagined, or recorded, as ball lightning. Indeed there is undoubted evidence of such discharges which are called St. Elmo's fire. In Dana's *Two Years Before the Mast*, there is the following account of this electrical phenomenon.

St Elmo's

"The main top gallant sail was to be taken in. The English lad and myself went up to furl it, and we had just got the bunt up when the mate called to us something we did not hear what — but supposing it to be the order to bear a hand, we hurried and made all fast, and came down feeling our way among the rigging. When we got down we found all hands looking aloft, and there directly over where we had been standing, upon the main top gallant, was a ball of light, which the sailors call a corposant (*Corpus Sancti*), and which the mate had called us to look at. They were all watching it carefully; for sailors have a notion that if the corposant rises in the rigging it is a sign of fair weather; but if it comes down there will be a storm. Unfortunately as an omen it came down and showed itself on the top gallant arm. We were off the yard in good season; for it is held a fatal sign to have the pale light of the corposant thrown on one's face. As it was the English lad did not feel comfortable at having it so near him, and directly over his head. In a few minutes it disappeared and showed itself again on the fore top gallant yard, and after playing for some time disappeared once more, and then the man on the forecastle pointed to it upon the flying jib boom. But our attention was drawn from watching this by the falling of some drops of rain and by a perceptible increase of darkness which seemed to add a new shade of darkness to the night. In a few minutes low grumbling thunder was heard and some random flashes of lightning came from the southwest. Every sail was taken in but the topsails. Still no squall appeared to be coming. A few puffs lifted the topsails, but they fell again to the mast, and all was as still as before. A moment more and a terrific flash and peal broke simultaneously upon us, and a cloud appeared to open directly over our heads and let down water in one body, like a falling ocean. We stood motionless and almost stupefied, yet no one had been struck. Peal after peal rattled over our heads with a sound which seemed actually to stop the breath in the body, and the 'speedy gleams' kept the whole ocean in a glare of light. . . .

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[1] Nuove esperienze sulle scintille elettriche, costituite da masse luminose che si muovono lentamente. R. Accademia delle scienze dell'Instituto di Bologna. 19 Maggio, 1895.

A ship is not often injured by lightning for the electricity is separated by the great number of points she presents, and the quantity of iron which she has scattered in various parts. The electric fluid ran over our anchors, topsails, and ties: yet no harm was done to us."

The appearance of ball lightning may be due to a phantasmagoria arising from nerves shattered by the noise and glare of lightning. The fact that the phenomenon has been observed by many whose descriptions of it fairly coincide may arise from a common psychological effect.

The noise of discharges six feet in length in a laboratory, I have said, is hardly that of the report of a pistol; but realization of the energy manifested in lightning grew as one studied these comparatively petty imitations of it.

The passage of the spark through the air mainly affects the air in a narrow channel along the path in the air. The spark in all cases seemed to prefer to break down the air to being, so to speak, dissipated in bodies of considerable resistance. A tube of glass was filled with a dilute solution of sulphate of copper; the spark passed between the glass and the sulphate of copper, as if it preferred an adherent layer of air to the liquid. If an orange was interposed between the terminals of the spark, it glowed in the dark like a Chinese lantern; the discharge passed between the rind and the pulp. These experiments indicate that much of the disruptive effects of lightning, the shattering of tree trunks is due to the expansion of confined air.

CHAPTER XI

THE AURORA

THE phenomena of electricity in thunder storms are not extremely varied. We have the lightning in its brilliant line of light and what is erroneously called heat lightning, which is nothing more than the light of distant line discharges which illuminate the sky at night, just as distant sparks on a trolley line cause a similar phenomenon. Ionisation partially explains the mechanism of the lightning discharge. When we turn to the other great manifestation of atmospheric electricity — the aurora, or northern lights — we find a greatly enlarged manifestation due to discharges taking place in air of greatly reduced pressure. Ordinary lightning occurs at a barometric pressure of not less than twenty inches of mercury and at a height not exceeding ten miles, while the aurora is only fairly imitated by discharges in rarified air at a pressure of less than an inch of mercury, that is, at heights greater than those of any mountains on the earth. The discharges in the varied forms of the northern lights are never line-like; they are diffused lights, more like extremely distant searchlights on a northern horizon; or on the southern horizon when viewed south of the equator. These lights are protean in shape, especially in high northern latitudes. Representations of their many beautiful forms can be found in the pages of the books on polar explorations.

The aurora shares with lightning our wondrous attention; it is even more magnificent in its manifestations than the lightning of the tempest. The range of the latter extends over eight months, while the aurora is generally seen in late August and the months of September and October; there are records of its occurrence in midwinter, but such occurrences are rare. The aurora often follows a marked change in temperature, and its display is seen at a comparatively early hour — nine or ten o'clock P.M. It is rarely seen in the spring time even after sudden changes of temperature. Since the aurora is more brilliant in regions near the north and south poles of the earth, we might expect that its occurrence would be more frequent as we approach the poles, but polar expeditions record very few aurora in regions close to the poles. Peary remarks that he had seen finer auroras in Maine than at the north pole. Professor Elihu Thomson, who has devoted much study to the aurora, has advanced the hypothesis that it is due to emanations, radioactive or otherwise, from the sun at the time of the equinoxes. It seems certain that magnetic storms on the sun are followed by displays of aurora on the earth. Magnetic disturbances may be caused by storms on the sun. Discharges in glass tubes filled with rarified gases are at certain pressures extremely sensitive to magnetism, indeed can show by the deviation of a line of discharge the position of the poles of the earth. When the light of the aurora is examined by the spectroscope a peculiar line is seen in its spectrum which has not been identified with any known gas. Professor Slipher of the Flagstaff Observatory has reason to believe that this line is always present in the heavens. Our knowledge of the aurora is greatly limited by the absence of simultaneous observations of it at the north and south poles of the earth. The questions in re-

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gard to it are most puzzling, and they are well stated in the treatise by Angot.[1] Since the publication of this treatise nothing has been conclusively learned in regard to this magnificent phenomenon, except its bearing upon the new science of radioactivity which we shall dwell upon later. The northern lights may be said to depict on the screen of the sky the phenomena of ionisation which will occupy our attention when we come to the subject of radioactivity.

Franklin once asked, "Is not the aurora the flashing of electrical fire from positive to negative clouds, at a great distance through the upper part of the atmosphere where the resistance is least?" When we give a general answer "Yes" to this question we conceal a much more intimate knowledge we have of electricity than can be imparted to the unscientific reader.

Magnetic storms on the surface of the sun are generally followed by exhibitions of auroras in the earth's atmosphere. It is certain that these exhibitions are electrical in nature; for they can be fairly imitated in laboratories by discharges of electricity through rarified gases.

Since the publication of Angot's book the phenomena of radioactivity have been discovered and it surmised that the so-called rays of radium may be influential in causing the northern lights. Auroras are influenced by conditions of the atmosphere and by electrical and magnetic storms, all of which have not been sufficiently studied, for observations are hindered by clouds. It would be interesting to discover whether wireless messages are disturbed by occurrences of the aurora.

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[1] International series. D. Appleton & Co., New York, 1897.

A discharge of electricity in the form of lightning, at the height of cumuli clouds—perhaps a thousand feet—requires many million volts. It requires a thousand volts to produce a spark just visible to the eye. As the height in the atmosphere increases the forked discharge becomes straighter: at a height where the barometric pressure is a thirtieth of that at the surface of the earth, in a discharge of lightning, if it occurs at that height, the forks would entirely disappear, and the discharge would be a uniform straight line. Beyond this point in the atmosphere we are in the region of auroral gleams. There is a stratum where less voltage is needed to produce electrical manifestations than in the stratum where cumuli clouds are present. Our attention is turned now more to discharges in air of low pressure — similar to auroral gleams — than to lightning; and observations of these discharges in glass tubes exhausted to low pressure have taken the place of observations with a revolving mirror of sparks in ordinary air. Beyond the region where the aurora exists there is a space extending to the sun's atmosphere where no lightning discharge can take place — a vacuum space — but across which electrons can pass under certain conditions.

Arrhenius has supposed that the particles of electricity — the electrons — are shot from the sun across this space and electrify our atmosphere. We have learned that there is a stratum of air of constant temperature surrounding the earth at a great height: there may be a stratum of electricity at the limit of our atmosphere which is constantly replenished when the electrons are drawn farther down toward the surface of the earth. This falling might occur when great movements of the atmosphere at the poles follow storms along the equator;

and great changes of barometric pressure are caused in extreme northern or southern regions.

The aurora are accompanied by electrical currents in the earth which are far wider spread than thunder storms. They frequently interrupt telegraphic communication. In the study of the discharges of electricity through rarified gases we may be said to have passed from Franklin's outlook to another height of immensely greater outlook, with a greatly extended horizon.

rarefied

The sun may be said to have a system of wireless telegraph between itself and the earth and the philosopher is trying to read the messages conveyed by the flashing of northern lights and the throbbing of earth currents.

The fact that the analyzed light of the aurora shows no correspondence to that of phosphorescence seems to show that the northern lights are not phosphorescent effects.

When an electrical discharge passes through a glass tube filled with air or gas at a pressure such as exists in the upper regions of the atmosphere, I have said, it manifests a great sensitiveness to magnetism. It is necessary to bear in mind that a magnet can be made by wrapping insulated wire, through which an electric current passes, around a bar of soft iron: an electromagnet thus produced is usually more serviceable than a permanent magnet. In certain of my experiments, the negative terminal — that by means of which the electric discharge left the glass vessel filled with air at a low pressure — consisted of such an electromagnet, its core of iron being enclosed in the tube. By this arrangement the lines of magnetic force were along those of the electrical discharge. The other terminal in the tube — the anode — consisted of an aluminum rod. At a pressure of the enclosed air which was in the neighborhood of that of the atmosphere fifty miles above the earth the light at the terminals before the electromagnet was excited was a feeble glow, but after an electrical current made the electromagnet a luminous discharge came out of the anode — where the discharge began — and then retreated very slowly into it. At a still lower pressure of the enclosed rarified air rings of light issued from the anode. I next placed an aluminum disk on the end of the iron rod; this disk thus constituted the surface of the cathode where the electric discharge left the glass tube. Under the effect of magnetism the violet light on this cathode was increased, and points of light revolved around the circumference of the disk. The electromagnet also exerted a marked effect on the light at the anode — where the discharge entered the tube. An electromagnet was then placed outside the tube — containing rarified air — at right angles to it, and at the middle of the tube; the striae of the discharge were bent by the magnetic influence. At very low pressures of the rarified air the discharge near the cathode can be made to fluctuate by the movements of a magnet when the latter is at a distance of even fifty feet.

CHAPTER XII

LIGHTNING BROUGHT TO EARTH

THE discovery of the electric current withdrew the attention of even philosophers from lightning and fixed it upon lightning brought to earth by the dynamo. We have, at the best, only a theory to account for the cause of lightning. We also merely theorise in regard to the production of an electrical current by means of the dynamo. It excites a current by the revolution of coils of wire between the poles of magnets — preferably electromagnets. A small amount of residual magnetism is almost always present in soft iron, induced by the magnetism of the earth. The revolving coils of the dynamo, constituting what is called its armature, are said to cut the magnetic lines of force of the iron poles between which the armature revolves. By a mechanical device the current thus generated is sent around the iron poles and by a law similar to that of compound interest electromagnets are built up, and stronger and stronger electrical currents therefore result from cutting stronger lines of magnetic force. This process goes on until the iron is saturated with magnetism. A coil of wire revolving in a magnetic field is a magic wand capable of lighting a city. The mechanical device for collecting and diverting a portion of the electric currents generated by the revolving coil or coils is called the commutator. In the so-called D. C. dynamo — direct current dynamo — the commutator charges all the to and fro currents which arise from the coils sweeping from the north poles to the field magnets to the south poles into one direction — we have thus what is called the D. C. current: a current in one direction, or what is often called the Edison current.

The effort of electrical engineers for many years was to perfect the direct current dynamo by improving the rectification of the alternating currents which result from the opposite direction of the current excited by movements of the revolving coils of the armature between poles of opposite names — north and south poles. The direct current is now a highly efficient machine. It changes at least eighty per cent of the power which revolves the coils of the dynamo into electrical currents. Why, therefore, does not a direct current dynamo answer our practical needs? In this type of dynamo there are usually only two magnetic poles between which the coils revolve. One could increase the number of poles and the number of armature coils, but such a dynamo would require a drum-shaped armature, with a complicated arrangement of commutators to rectify the currents excited if the throbs were to be merged in what appears to be a steady direct current.

A pulsating or alternating current dynamo is now largely competing with the direct current dynamo in practical electricity. In the early days of the dynamo the chief effort was to so perfect the mechanism that the alternating currents which naturally arise from a coil passing from the face of a north pole and then to that of a south pole — currents in opposite directions — should be sent in the same direction. Now the alternating current dynamo is so constructed with a number of electromagnetic poles or what are termed field magnets that powerful currents are conserved in opposite directions. The great advantage of the alternating current — the A. C. current — is that one can use transformers: one can step up or step down — to speak in commercial language — that is increase the electromotive force or decrease it by means of induction coils. Any change of current in an electric circuit instantly excites a change in a neighboring circuit by what is termed electromagnetic induction. The discovery of this was Faraday's great work. In his apparatus he gave this induction free play: he made no attempt to commute currents, to direct alternating inductive currents into one direction. We are now, in practical electricity, coming back to the unhampered play of induction, so to speak, observed by Faraday. The formation of the alternating current dynamo is a more natural one than that of the direct current dynamo. In the free exhibition of electricity — in a stroke of lightning — an electrical throb excites a current in all neighboring conductors. The familiarly called shocking or Ruhmkorf coils used in medical practice, and once by professors of physics to produce electrical sparks are examples of electromagnetic induction: an interruption or alternation of current in one coil produces a current in an independent coil. The telephone transmitting apparatus is another example: an alternating current awakened by the changing vibrations of the human voice is sent through one coil — the primary of a little Ruhmkorf coil — and excites similar vibrations or alternations in an independent coil. We have thus the transformer: we step up from a comparatively low electromotive force, in a microphone circuit, to a higher electromotive force on the telephone line. This higher electromotive force is essential for long distance transmission either of speech or electrical power. We realize this by a consideration of the fundamental law of electrical circuits, namely that the current is equal to the electromotive force by the resistance — what is known as Ohm's law. It will be seen that by transforming to a higher electromotive force we can overcome a larger resistance. The reverse also holds; we can transform from a high electromotive force to a smaller. This reverse method is employed in the use of the alternating current in lighting houses: a thousand-volt circuit on the street can be transformed, by means of induction coils, into one of thirty or forty electromotive force with a corresponding strength of current. In electric welding a similar transformation is used. It will be seen that the alternating current is far more flexible than the direct current. It is interesting to note how the old Ruhmkorf coil of the lecture room has become a commercial instrument. The D. C. current cannot excite transformers: it is a uniform current without alternations, and without rapid changes of current no inductive effects result.

The development of the alternating current dynamo was almost immediately followed by the invention of the alternating current motor — the so-called one-phase and two-phase motors. One alternating current machine can drive another, but it takes a short interval of time to start an alternating current motor; the direct current dynamo also can drive another direct current dynamo; the direct current starts or stops a motor instantly. The latter is, therefore, used on trolley lines or in cases where quick action is necessary. It is evident that after long distance transmission of electrical currents one can by means of an alternating motor revolve a shaft which can set in motion a direct current dynamo and thus change an alternating system into a direct system. It is seen how flexible the alternating current is.

The electric transformer — that is the old Ruhmkorf coil, one exciting coil, through which an alternating current passes, and a closely adjoining independent coil in which a current arises from electromagnetic induction — in the hands of Tesla and Elihu Thomson, has produced very powerful electric discharges. Why, therefore, in view of the ready use and flexibility of the alternating current should one seek to employ a storage battery? The answer is that in scientific investigations, apart from the investigation of lightning, it is highly desirable to have a perfectly steady direct current: the current from a direct current dynamo always fluctuates slightly. My object in forming a large battery plant was to have a strong steady current and a high electromotive force for spectroscopic study, not so much for the study of lightning: the use of condensers enabled me to imitate the phenomena of lightning very closely by the discharge of condensers, one after another — the method of cascade — and to repeat Franklin's experiments on a much larger scale.

We are obliged to confess that with all the aid of the electric current we have not advanced much farther than Franklin in our study of lightning. The attention of scientific men and men interested in the practical employments of electricity inventors has been directed away from the sky to the problems of conduction of the electrical current in metals. We are now witnessing a remarkable return to the free exhibition of electricity in rarified air, which we shall discuss under the head of radioactivity. After diverging apparently so completely from the field of Franklin's studies we seem to be returning in a measure to that field. But we have not solved the problem of the flow of the electrical current in metals in leaving it for manifestations of electricity in freer media. But we are coming back with the electron which may enlighten us greatly in regard to that flow.

CHAPTER XIII

THE ELECTRIC CURRENT

WHEN Tyndall wrote his *Heat as a Mode of Motion* there was a complete ignorance of what he might have termed "a mode of motion of electricity." In his work of over five hundred pages, I have noted, there are only two direct references to electricity; and these are used to illustrate the phenomena of heat. In one of these references he gives the following table of the comparative conductivity of certain metals for heat and electricity: —

Name of substance	Electrical conductivity	Heat conductivity
Silver	100	100
Copper	73	74
Gold	59	53
Brass	22	24
Tin	23	15
Iron	13	12
Lead	11	9
Platinum	10	8
German Silver	6	6
Bismuth	2	2

Tyndall says, "This table shows that in regard to their conductive powers the metals differ very widely from each other. Calling, for instance, the conductive power of silver 100, that of German silver is only 6. . . . Our table, however, exhibits one important connection between heat and electricity. Beside the numbers expressing conductivity for heat, MM. Wiedeman and Franz have placed the numbers expressing the conductivity of the same metals for electricity. They run side by side: the good conductor of heat is the good conductor of electricity, and the bad conductor of heat is the bad conductor of electricity. Thus we may infer that the physical quality which interferes with the transmission of heat interferes in a proportionate degree with the transmission of electricity. This common susceptibility of both forces indicates a relationship which further investigations will no doubt clear up."

He says in another place, "Let me point out another evidence of communion between heat and electricity. I have here a length of wire made up of two different kinds of wire: there are three pieces of platinum, each four or five feet long, and three pieces of silver of the same length and thickness. It is a proved fact that the amount of heat developed in a wire by a current of electricity is directly proportional to the resistance of the wire. We may figure the atoms as throwing themselves as barriers across the track of the electric currents — knocking against them, and imparting their motion, and rendering the wire hot. In the case of the good conductor on the contrary, the current may be figured as gliding freely around the atoms without disturbing them in any great degree. I will now send the current from a battery of twenty grove cells through this compound wire. You see three spaces white hot, and three dark spaces between them. The white hot portions of the wire are platinum, and the dark portions are silver. The electric current breaks impetuously upon the molecules of platinum, while it glides with little resistance among the atoms of silver, thus producing in the metals different calorific effects." Tyndall further remarks, "May not the condensed ether which surrounds the atoms be the vehicle of electric currents?" In the differences of electrical conductivity shown by Tyndall's table may be said to reside the mystery of the electrical current. When the cause of these differences is explained we shall have much knowledge of action of the electron: here is a fertile field for inquiry. At present the attention of physicists and chemists is fixed upon the freeing of the electron from matter by disintegration of the latter. If we could succeed in reducing the electrical resistance of pure copper even ten per cent we should cause almost a revolution in the practical employments of electricity. It will be noted that Tyndall seemed to have had an intimation of electronic action. The electrical resistance of metals apparently is due to some restraint of the motion of electrons which is relatively absent in gases, for my experiments show that their activity in the electric spark in air does not exhibit an increase of resistance with an increase of length of the sparks.

Before the identification of the electron, the action of the dynamo was thought of as a disturbance of the ether of space, a disturbance of what Faraday called the electrotonic state of the ether: now we are inclining to a more discreet conception in which the electron plays a supreme part. The electric current from a chemical battery separates ions in a fluid by means of an electromotive force — the voltage of the battery — and the current flows through the fluid or electrolyte and the metallic circuit connecting the poles of the battery. In the case of the dynamo the current is generated by motion not, however, in ether alone; but in an ether in which there is an assemblage of electrons in iron. Ampere accounted for magnetism by the supposition of electric currents circulating about the particles of iron, thus forming an electromagnet of a bar of steel. Now we have a theory of orbital movements of electrons about the atom of iron or steel forming what are termed magnetons peculiar to iron and steel. The usual practice of magnetizing which consists in passing currents of electricity around soft iron may direct the electrons in definite paths. These directed electrons disturb a neutral state in a metallic conductor when it moves near their state in iron and excite an electrical current in the moving wire which is evidence of a movement of electrons. What the mechanism is of this movement in a conducting wire is still a mystery. It is conceived that an electron in motion has, so to speak, a magnetic aureole about it, lines of magnetic force, analogous to those about a particle of magnetized steel.

There are two manifestations of the electric current which are the most evident to the ordinary observer: these are the heating effect of the current and its magnetic relations. We see a constant exemplification of the two phenomena in the lighting of our cities and in the trolley systems. The last depends upon the magnetism excited in iron by the electric current. This current generated at a central station by dynamos, actuates the motors on the cars. The heating is due to the resistance of the electrical circuits and this heating is practically always the accompaniment of the electrical current: the slightest change in the molecular condition of a conductor is shown by a fluctuation in an electrical current which flows through the conductor: heat can produce such a change and these fluctuations afford a very delicate means of measuring both the heat and the electricity. When a grid of wires, through which an electrical current is flowing, is exposed to a source of heat a change of electrical resistance is produced in the grid, and by means of this change in resistance the amount of heat received can be measured. During the late war this phenomenon of the change of electrical resistance by changes in temperature was employed to detect the position of cannon. A piece of platinum cloth forming a part of an electrical circuit and heated by the current was exposed to the puffs of air resulting from the explosions of the cannon. These puffs of air cooled the incandescent platinum cloth and therefore changed its resistance. This change was measured on what is called a string galvanometer, which consists of a fine wire stretched between the poles of an electromagnet. When an electrical current flows through the stretched wire it is attracted to one pole or the other of the magnet. The amount of this deviation is recorded on a photographic film. The sound waves, heat, electricity and magnetism combine in this detection system. An instrument, called the bolometer which measures heat by means of changes in electrical resistance — devised by Professor Langley, of aeronautic fame — is used to detect fluctuations in the heat of the sun. The heating effect of the electrical current is being used more and more in the arts, and in domestic uses; and some believe that electricity from water power will in time supersede coal in the production of heat. This belief is strengthened by the constant improvements in the applications of electricity to the problems of the production of light and transmission of power. In thirty years we have seen a remarkable development in the production of light by the electric current. The resistance afforded by carbon to produce heat and light was at first the only resistance employed in developing light and heat by electricity, but now the carbon filaments in the glass bulbs known as Edison lights have been entirely superseded by metallic filaments which are almost as fine as cobwebs: the Edison light is changed, except in name. A method has been discovered of drawing out the metal tungsten, for instance, into fine wires.

The electrical resistance is supposed to be due to some friction or other activity of the electrons aroused in the flow of the electrical current. These electrons are so minute that they cannot be detected by the most resolving microscope. The study of lightning in the region where Franklin studied it has ceased to add greatly to our knowledge of electricity; although it may increase our acquaintance with meteorological phenomena. The study of electrical sparks — the infinitesimal manifestations of lightning — has been supplanted by that of silent discharges of electricity like the aurora. The study of the aurora in the heavens has passed through the same course as that of lightning: observations of it in the sky have been followed by the study of similar manifestations of electricity in rarified air enclosed in glass tubes. Thus the thin air in which the spectacle of the aurora occurs has been imitated, and the silent lightning can be studied at our leisure in our laboratories — evanescent glows can be converted into long enduring ones. The effects of silent discharges of lightning in thin air — the aurora — present a much greater range of phenomena than the discharge of lightning: there is the range of color — yellow, crimson, and violet — in streamers which flash from the apparent region of the poles of the earth to the neighborhood of the zenith. The most significant phenomenon is the effect of the magnetism of the earth on these streamers: they seem to emanate from the region of the poles; they cap the earth with a crown of coruscating jewels, and they reveal the influence of a giant adjunct to electricity, magnetism, which lightning at the earth's surface does not reveal. Auroral discharges of electricity are far more cosmopolitan than those of lightning. While the latter is extremely local — limited to a few square miles of area — the auroral discharges may extend even around the earth. The aurora represents today the field in which the most significant advances are being made in rarefied electricity — the field of its silent discharges in rarified air. It is not necessary to fly to high regions to study, if it were possible, the aurora; or to go to Baffin Bay or to Nome to observe it. Its phenomena can be studied in a laboratory, by submitting rarified air enclosed in glass tubes to electric discharges influenced by magnetic poles; thus we have an aurora always at command. The greatest advances both in theory and in practical applications of electromagnetism have been made by study of the aurora brought to earth. The words applied to Franklin, *Eripuit fulmen a caelo* can also be applied to the first scientific man who studied electric discharges in thin air.

I have endeavored to show, thus far, that we have reached an impasse in our study of lightning and of electric sparks in ordinary air. In these resounding manifestations of electricity there is no manifestation of electromagnetism, to which force is due all our theoretical knowledge and practical applications of electricity from the time of Franklin. We now leave our best efforts to extend his study of lightning to ascend to a higher region — that of the aurora — and follow the most remarkable extension of our knowledge of electricity which has resulted from the study of electric discharges in thin air — an extension which is very marked in the new subject of radioactivity.

CHAPTER XIV

THE PARTICLE OF THE ELECTRIC CURRENT

TYNDALL'S treatise on the relations of heat to motion marked an epoch in physical science: we are now entering upon greatly enlarged views of motion. In the consideration of the theory of the electric nature of energy—the electromagnetic theory—we conceive of a universal ether by means of which the electrodynamic waves travel through space. This medium is supposed by some to be continuous, by others to have a grained structure. It is certainly easier to conceive of a grained structure than of continuous matter: water seems to be a type of continuity, but we know that it is made up of molecules or atoms of hydrogen and oxygen. Water is incompressible, the ether of space is also supposed to be incompressible. Waves of water travel just as the waves of energy traverse space: a cork on water moves up and down at right angles to the direction of propagation of a wave, the undulations of the electrodynamic waves in the ether are also at right angles to the direction of the waves. Some think in regarding the movement of waves in water that the ether may be composed of infinitely small particles which constitute an ocean. The fluid theories of electricity which prevailed in Franklin's time had the same idea of continuity that the present theory of ether has. We have freed ourselves from a belief in fluid theories and seem to advance to a theory of grained structure of the ether. We shall see in considering the new subject of photo-electricity the effect of ultra-violet light upon electrical charges that grave doubts are rising in regard to the continuous nature of the ether.

The electromagnetic waves are revealed in the release of chemical bonds and in the phenomena of photo-electricity. When an electrical current arises from an electrodynamical change in what we call matter, or from electromagnetism, as in the motion of the dynamo, and flows through acidulated water, this is decomposed into oxygen and hydrogen gases. Oxygen is liberated at the anode/ metal plate, called the ~~cati~~on, the terminal by which the electric current enters the liquid, and hydrogen at the c/ ~~k~~athods, the terminal by which the current leaves it. The acidulated liquid is called an electrolyte, and the current travels through it by means of charged particles called ions. From the amount of hydrogen gas liberated the size of the hydrogen atom can be calculated. In general we say that the passage of the current is due to streams of ions, moving in opposite directions through the electrolyte, carrying plus and negative charges with them. The charged ions are supposed to move independently of each other. The force required to drive the ions may be very great; for instance the aggregate force required to drive one gram (.002 of a pound) of potassium ions with a velocity of one centimetre (.4 of an inch) per second through a very dilute solution is equal to the weight 83.6 pounds avoirdupois. It has been suggested that the frictional resistance due to the action of an ion arises from the viscosity of the liquid, and that the ion is analogous to a body of some size urged through a viscous medium rather than to a particle of molecular dimensions finding its way through a crowd of molecules of similar magnitude. It is considered that an electrolyte consists of dissociated ions and that these ions can move independently of each other when no current flows.

In liquids the ions are always combined with matter: there are indications that an ion in a liquid consists of an electrified part of the molecule of the dissolved salt with an attendant atmosphere of the solution around it. The motion of ions in liquids always involves the movement of atoms or molecules (groups of atoms). An atom with an extra corpuscle is called a univalent negative atom; an atom with one corpuscle detached is a univalent positive atom. In gases the electrons sometimes travel alone: they can traverse space where there is no matter. The ions in gases must not be confounded with the ions in liquids; for the gaseous ion may be reduced to merely an electrical charge — the electron. The atmosphere about us always has ions, some charged positively and others negatively: an interchange is always in action.[1]

The corpuscle we have referred to as something attached to the atom is what is now called the electron, a body much smaller than the atom. Its recognition is due largely to the X-rays. When these rays traverse a gas or vapor they separate the negative ions from neutral molecules: they are said to ionise the medium. The process becomes evident both from the increased ability of the gas to transmit an electric current and the formation of a cloud of vapor which discloses the size of the electrons from the influence of gravitation on the fall of the vapor. The preliminary condition, in the formation of this cloud of vapor, is an interesting example of how a body far too small to be seen betrays itself by its connection with matter. When air is suddenly rarified by a stroke of an air pump, a cloud of vapor is formed due to the deposition of moisture on particles of dust in the air. Aitken showed that if the air is drawn into the receiver of the air pump through cotton wool and then suddenly rarified no vapor is formed. If now one thus deprives a vertical column of air by this means of dust and submits it to the X-rays, a cloud of vapor is formed by the association of the electron with matter. The X-rays ionise the air and produce positively and negatively charged carriers of electricity. From the rate of fall of the vapor under the effect of gravity, and from the law of movement of particles in a viscous medium the physicists and mathematicians of Cambridge University, England, determined the size of the electron. Later, Professor Millikan of the University of Chicago determined this size by submitting a fine spray of oil injected between two plates, one charged positively, the other negatively to the ionising effect of the X-rays — balancing the ions produced by opposing the force of gravity to the attractive forces of the electrical charged plates — thus suspending the electron like Mahomet's coffin in air. The space between the plates was illuminated by a powerful electric light and the ions were observed through a microscope.

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[1] *Encyclopaedia Britannica.*

" These experiments have shown that the ratio of the charge carried by the electron to its mass is one divided by ten raised to the seventh power. The ration of the charge to the mass in the case of the hydrogen atom, produced by the decomposition of water by electricity, is one divided by ten raised to the fourth power. The mass of the electron is therefore one-thousandth of that of the hydrogen atom, and is the smallest body recognized in physics and chemistry."[1] The electron cannot be seen but its associations with matter can be observed. Its impact on suitably prepared screens produces light; its motions are revealed by magnetism, for as an electron flies its path is diverted by magnetism; it is in evidence in an electrical current. We shall see that it plays the principal rôle in wireless telegraphy.

The X-rays, thus, have led to the determination of the electrons. The latter in turn have assisted in the manifestation of these rays. This fact is illustrated by the latest form of X-ray tube which is due to Dr. W. D. Coolidge. In a large bulb of glass highly exhausted, a small metallic filament is inserted, which is similar to the filament of an ordinary electric light bulb. Opposite this filament at the other end of the bulb is a terminal of tungsten — an anvil — to receive the electrons which are shot forth from the filament when it is made incandescent by a storage battery current and when an alternating current of high electromotive force is connected to the filament and to the anvil. Only the negative electrons are driven from the filament to the anvil: the alternating current is thus said to be rectified; it passes only in one direction, the positive alternation is suppressed. When the electrons are driven out of a hot wire by a strong electromotive force, as in the case of the Coolidge X-ray tube, their velocity can reach a very high value: they are projectiles and their impact on a metallic target, such as the tungsten target in the X-ray tube, can raise it to a white heat, although in their flight from the hot filament to the target they are absolutely invisible and the bulb shows no light. The X-rays emanate only from the anvil.

[1] Rutherford, *Radioactivity*.

Sir Isaac Newton supposed that light was caused by infinitely small corpuscles shot forth with very great velocity from the sun. This theory demanded that light should be propagated faster through water than through air; on the contrary experiments show that it is propagated more slowly. The phenomenon of the interference of light has established firmly the wave theory. Whether we regard the ocean of space as composed of infinitely small particles or as consisting of a continuous medium, the ether, the vibration of the electrodynamic waves are at right angles to the direction of the waves. Since a heavy shower of rain can flatten the waves in water I endeavored to discover whether waves of light sent athwart the stream of electrons in the Coolidge tube could be modified in a similar way. No effect could be observed.

On the supposition that the ocean of space is composed of particles, these particles would seem to be infinitely smaller than the electrons and can pass unimpeded even through them, if the electrons are matter — just as the supposable ether passes through the earth. The fact that an alternating current of electricity can be made unidirectional—that is compelled to pass only in one direction — by emerging from a hot wire, is made use of both in studying the interior of the human body and also in transmitting and receiving wireless messages. At one time, in the early days of wireless telegraphy, the electric spark was employed to excite waves in the ether which were caught or arrested by the aerial at the receiving station. The sender and receiver now are of the same form. A highly exhausted glass bulb somewhat smaller than an ordinary electric bulb is provided with a metallic filament which is made incandescent by a storage battery; this filament is surrounded or is opposite a metallic net or terminal; the filament and the net or terminal are connected to the aerial which receives or sends the wireless messages. The alternating electric currents impressed by the human voice on the ether by means of a transmitter and a battery travel on the negative electrons more readily than on the positive electrons: the alternating current is thus said to be rectified. An ordinary electric light bulb can thus be made a receiver of wireless messages by inserting a terminal which can be connected to the antennae of the receiving wireless station. It can also serve as a transmitter of wireless telephone communications. The X-ray tube can serve also as a transmitter or receiver of wireless messages, by the use of a relay system.

We have also an example of the rectification of an alternating electric current in the action of the mercury rectifier now employed to charge storage batteries which run electric automobiles. The alternating current flows between a surface of mercury and a metallic terminal in a glass bulb highly exhausted of air; the electric current passes only in one direction, and can therefore be used to charge batteries. If it alternated the charging effect in one direction would be neutralized by that in the opposite direction: the negative electrons thrown off in the mercury bulb rectifier can serve by means of a battery to relay a feeble wireless message which may pass through the bulb. All of these devices which employ the negative electrons to obtain increased conductivity are called amplifiers. It is seen that we have a comparative insight into the conditions for the passage of an electric current through highly exhausted media: its flow through metallic conductors — such as copper wires — is still little understood; the negative electron, even there, is probably the important factor.

The passage of an electric current through a conducting liquid is explained by the phenomenon of ionisation, the formation of ions which carry positive and negative charges. These charges accumulated on the terminals of a storage battery or a chemical cell produce a spark when they recombine. This spark of recombination is not strong enough to be seen with the number of cells usually employed in automobiles, for instance. In the process of charging a storage battery the positive ions proceed to the plus or positive pole of the battery, the negative or minus ions accumulate at the negative pole: when these poles are connected by a wire, an electric current results. We have a reasonable view of the process of conduction of the current through the liquid of the battery but at present we have little insight in regard to its conduction through a metal. All we know is that the current meets with a resistance and heats the conductor: there is, therefore, internal work done by electricity in passing through or slipping by molecules or atoms. Electrons are analogous in dimensions to the bacilli which pass through the most compact partitions. They cannot be recognized by photography in a metallic conductor: they do not modify apparently the passage of light through a strip of gold foil which makes part of an electrical circuit. The light transmitted by the thin gold foil — a greenish light — is unaltered by the presence of the electrons. Cannot we detect their presence by magnetism? Suppose that a very thin sheet of metal — similar to a strip of gold foil — should be inserted between the poles of a strong electromagnet and that an electric current should be made to flow through the sheet. Would not the current through the strip be modified by the magnetic force? would it not flare out from an unmodified course and seek a new direction in the sheet much as an electric spark flares in free air between the poles of a magnet, for electrons are very sensitive to magnetic force? This effect on an electric current circulating in a thin metallic sheet has been detected by Professor Hall of Harvard University, and is known as the Hall effect: it is undoubtedly an effect upon electrons, revealing their presence.

The heating produced by an electric current seems to be an irrefragable evidence of the activity of the electrons in a conductor: while they are in an excited state, cannot they be induced to leave a hot wire — cannot they be squeezed out of it, so to speak, or made to ooze out? Do they not leave the hot wire under favorable circumstances? The answer is given in the new subject called thermionics, which relates to the most remarkable development of the theory of ionisation in X-rays and wireless telegraphy and telephony. In this chapter I described the latest form of X-ray tube — the Coolidge tube — in which the electrons driven out of a heated wire — through which an electrical current flows — by a strong electromotive force strike a metallic target, raise it to a white heat, and excite X-rays. The space in the exhausted Coolidge bulb is absolutely dark; the electrons are invisible in their flight; and it is only when a fluorescent screen or a photographic plate is used opposite to the metallic target that the light effect of the striking electrons can be observed.

The ordinary method of determining whether the X-rays are of sufficient strength for surgical purposes is to observe the light they excite upon screens covered with suitable fluorescent substances — salts of barium, for instance, after the electrons have left the surface of the cathode. Magnetism also has no effect upon the passage of the electrons instrumental in the production of the X-rays; it has, however, great effect upon the cathode rays which appear when the vacuum of exhausted tubes, through which electrical discharges pass, does not reach that of the X-ray stage.

If physicists had been provided with suitable fluorescent screens — sufficient in size — it is probable that the X-rays would have been discovered earlier. It is said that Röntgen first observed the skeleton of his hand by interposing the hand between a small screen and the negative terminal of a highly exhausted discharge tube. An assistant had previously noticed that some photographic plates enclosed in a light-tight box had become blackened. Like so many great discoveries that of the X-rays was accidental: the chief function of science is to amplify and perfect such discoveries.

The fluorescent effects produced by the electrons in striking matter connects them in a species of relationship with violet light. It is related that a workman employed to sort certain crystals of minerals which entered into a manufactured article used an electric arc light. One night the carbon terminals of this light were burnt out and he supplied their place by two nails. Immediately the minerals could be separated by a difference of hue — crystals of one metal glowed with a red light, crystals of another exhibited a green or blue light. This was due to fluorescence of the short waves of light — the ultra-violet rays produced by the iron arc. If one should explore a cavern with an electric arc excited between pieces of iron one might see walls illumined as if by the presence of diamonds, sapphires, and rubies: science realizes the story of Alladin's lamp. In the relation of the phenomena of ionisation produced by violet light, by cathode rays and X-rays we see a family relationship which has culminated in a detection of the electron.

What a transformation the discovery of the particle of electricity has caused in our views of electricity! These views have been more or less superficial, except in regard to the great generalization of Maxwell that light and heat are electromagnetic in nature. We have taken the electrical current and its magnetic effect as a whole: now we are examining minutely interior mechanisms. There has been a revolution in the views of physicists, but not more so than that which these new views have caused in the field of chemistry. The discovery of radium was not so much a chemical discovery as a physical one; for a physicist, Becquerel, who had studied singular photographic manifestations of uranium, suggested to the Curies a chemical investigation of the cause of these manifestations. When radium was isolated its physical qualities were its remarkable ones, and were studied almost entirely by physicists: these philosophers may be said to have appropriated radium from the chemists and in so doing have given the apparent foundations of chemistry a great wrench. The long-held conception of the atom is attacked by the physicists. The physicists claim that atoms differ from each other only in the arrangement and number of their component particles of electricity, or electrons. When these electrons leave the atom, under electrical stress, there is an apparent disintegration of matter. The atomic disintegration is very unlike chemical changes which had long been studied by chemists and which characterized the science of chemistry. They are also independent of temperature which has always been considered such a controlling factor in chemistry. Particles of gas are suddenly set into rapid motion when they strike, for instance, on a hot surface; electrons when they escape from atoms are not set in motion by external causes, but manifest a velocity which was a factor in their orbital motions around the atom. It is as if the earth, freed from the attraction to the sun, should be projected into space — liberated not by some change of heat, but by a mysterious impact due to electrical and magnetic forces.

The recognition of what may be called spontaneous disintegration of matter, by physicists, from the study of radium, has given physical and chemical science a new method of analysis and is profoundly changing the subject of physics, especially in the field of relations of electricity to matter. In order to obtain a comprehension of the new development in electrical science it is necessary to enter into more detailed accounts of the various steps which have led to this new development of theory and to the practical employment of the electron in the X-rays and in wireless telegraphy. We have spoken of the Coolidge X-ray tube, which is, perhaps, the first striking application of thermionics.

There is an interesting analogy between the Coolidge X-ray tube and the latest apparatus employed in wireless telegraphy and telephony. In one case electricity opens a way into the mysteries of the human body, in the other it traverses the vacuum of space. The Coolidge tube could be used also in wireless telegraphy, but a bulb similar to an ordinary Edison light bulb is used;

indeed such a bulb so common in electrical lighting can be used both to send wireless messages and to receive them. Opposite the usual incandescent filament in the bulb is placed another terminal, usually in the form of a grid. The antennae of the wireless are connected to the glowing filament, to the grid, and to the ground. The electromotive force on the antennae find a passage on the negative electrons oozing out of the glowing filament and the resulting current can be detected on a telephone suitably connected with the antennae. A transmitter also can serve to impress an electrical fluctuation on the antennae, which is transmitted through the ether of space. Such bulbs provided with incandescent filaments and with opposed grids have come into general use for the detection of minute electrical currents. They promise to entirely supersede the use of the electrical spark in wireless telegraphy. In thermionics we have the greatest practical development in electricity since the discovery of the telephone.

CHAPTER XV

LIGHT AND THE ELECTRON

SINCE it is believed that the waves of light have magnetic relations the bearing of these upon the electron theory has become a vast extension of the subject of spectrum analysis. Light can be said to be magnetic. Long before the electromagnetic hypothesis was enunciated by Maxwell, Mrs. Somerville tried the effect of violet light upon a magnet, and claimed to have observed an effect. This effect has not been found by subsequent observers. It is certain, however, that magnetism can affect a beam of light. Faraday, for instance, caused a change in a plane of polarised light, that is, a plane in which the vibrations of light have been confined by passing such a beam of polarised light through a column of dense glass which formed the core of a powerful electromagnet. Since Faraday's experiment the relations of magnetism to light have received great extension: the electron theory of electrical manifestations depends upon these relations.

We are now entering upon a great development of spectrum analysis in which magnetism plays a predominant part. It is said that Bunsen and Kirchoff, on discovering that the bright line emitted by sodium vapor, when salt is thrown into a flame, became a dark line, or was reversed, when the light passed through a colder layer of the vapor, abandoned observation of this fact and retired for earnest reflection which led to their statement of the fundamental law of spectrum analysis, that a colder vapor of a gas or metallic vapor absorbs the energy of the highly heated vapor. In scientific language we say that light of the same degree or refrangibility that is emitted is absorbed by a colder vapor. This law has revealed the constitution of the stars. Considered purely as a phenomenon of light the light spectrum has been of the greatest service not only to the astronomer but to the chemist. Considered now from the electromagnetic point of view it has a surpassing interest to the theoretical electrician. That branch of electricity, magnetism, which was so little considered in the time of Franklin, has now revealed the motions of the electron — the particle of electricity. Fifty years ago spectrum analysis was considered entirely from the point of view of the motion of molecules or atoms and wave lengths of light. In the visible spectrum these wave lengths ran from approximately one fifty-thousandth of an inch in the red to a length of one sixty-thousandth of an inch in the ultra-violet. There is another phenomenon of light which is of great importance to the observer of star motions: this phenomenon is called the Doppler principle. It is exemplified in the well known fact that a locomotive whistle sounds louder when a train approaches an observer and lower when it recedes. The length of a sound wave corresponds to the pitch of the notes. In the case of light there is a similar phenomenon. The lines in the spectrum of a star show a similar approach and recession as the star nears or recedes from the observer. Now there is another displacement of spectral lines which leads us farther into the mysteries of the motions of electrons. This displacement is an evidence of the effect of magnetism on light. Detection of this influence was due to the theoretical work of Lorentz and its experimental verification by Zeeman — two Hollanders who have continued Hugyen's work in the subject of light. It is interesting to observe that we owe to Holland in the person of Hugyens fundamental concepts of the wave theory of light, and now a great extension of it in the domain of electromagnetism.

Zeeman placed a flame colored by sodium between the poles of a powerful electromagnet and observed a deviation of the lines of the spectrum. H. A. Lorentz had proved by mathematical analysis that the result was to be expected from the theory of electrons. A further study by Zeeman and many others has shown that the electrons in electric discharges and probably in the lightning discharge are greatly influenced by magnetism. Professor Hale of Mt. Wilson Observatory has discovered that solar spectral lines are affected by the magnetism of the sun; the theories of the arrangement of the lines in spectra of gases and vapor of metals depend greatly upon the influence of magnetism on electrons. The multitude of lines in the spectra of most metals is now regarded as the result of atomic motions largely controlled by the presence of electrons.

Spectrum analysis has captivated the imagination more by its revelations of the constitution of the heavenly bodies than by its analysis of the light of incandescent gases and of the vapor of metals. The field of its employment on the earth has seemed in public estimation to lack the extensiveness of its use in astronomy. But the universe of the infinitely small revealed in all its complexity by the discovery of the electron is now a field opened to the study of the physicists, in which spectrum analysis, singularly enough, reveals the motions of objects which cannot be seen. The physicist, it may be said, has penetrated farther into the mystery of space than the astronomer. The use of spectrum analysis in the heavens is limited to visible objects and affords no clue beyond the faintest nebula: it rests with the triumph of the analysis of the constitution of nebulae: it finds its limit in the absence of light — something to analyse. Electrical analysis promises to go farther than spectrum analysis.

We consider the minuteness of the particle of electricity with wonder and we marvel at the speed with which it travels; but with how much greater wonder we must consider its electromagnetic effects. When the electron travels in a straight line it maintains its energy intact, the magnetic aureole about it — due to the magnetic lines of force — is unaltered: the electron does not give out energy unless its motion is stopped or changed. If it flies at a uniform rate across the space between us and the sun it holds the energy with which it was originally endowed. If its motion is altered — increased or retarded — there is a loss of energy due to electromagnetic radiation.

From a particle hardly visible to the eye it is estimated that 30,000,000 of particles fly off every second. If the atomic energy of an ounce of matter could be utilized, it is estimated by Sir Oliver Lodge it would be sufficient to raise the German ships sunk in the Scapa Flow to the height of the tops of the Scottish mountains.

It is calculated that the particle of electricity — the electron — can pass through 10,000 atoms without coming near enough to them to disturb them, and the swarm of meteors constituting the ring of Saturn, which revolves about the planet, represents to certain mathematicians orbital movements of the electrons. To account for magnetism we have a magneton, with electric charges, revolving about the atom of iron or steel, the movements of which cause the phenomenon of magnetism. Thus the theory of Ampere, that this phenomenon is caused by electric currents circulating about a magnet, takes another more intimate form. There is a danger of the application of false analogies in our remarkable increase of knowledge of the extent of the invisible and infinitesimal world. Should we conclude from the well known fact that radium throws off millions of particles, and thus slowly disintegrates, that all metallic bodies can, under certain conditions, liberate an immense amount of energy? Can we also conclude that since the magnetism of iron and steel can reasonably be explained by the revolution of electrons about atoms that there are revolutions of electrons about the atoms of a pin, which, however, are restrained by some configuration from manifesting attraction?

The fact that the attraction of gravitation is expressed by the same law as that of magnetism and electricity, that is, by the product of attracting bodies divided by the square of the distance between them, leads to a reasonable belief that there is a connection between gravitation and electrodynamics.

One concludes that the atoms of all bodies are very complex and are in part built up of electrons. We therefore enter into a field of mathematical conjecture analogous to that which deals with the grouping of suns and planets. Questions in regard to radiations of energy from movements of electrical charges are analogous to those which arise in the study of suns and planets. Any alteration of the velocity of a moving charge is accompanied by a radiation from it. An electron moving in a circular orbit is a powerful radiator of energy since it is constantly accelerated toward the centre. An atom moving in an orbit of radius equal to the radius of an atom (approximately one two hundred and fifty millionth of an inch) would lose most of its energy in a small fraction of a second even if its original velocity was nearly equal to the velocity of light. Professor J. J. Thomson, however, has conceived of a stable system consisting of a number of electrons arranged on the circumference of a circle, which move with a constant velocity around the ring (Rutherford, *Radioactivity*). Sir J. J. Thomson suggests that each atom consists of a positive charge of electrification in which circulates negative electrons, which are held in equilibrium by the attraction between the negative and positive elements — the size of the positive element being much larger than that of the negative elements. Rutherford, however, proved experimentally that a central positive charge must fill a very small space in regard to the excursions of the negative electrons, and he was led to propose a theory that the positive charge of the atom is small and that the negative electron or electrons are not within the positive sphere of electrification, but that they circulate outside of it in large orbits about the atoms. It is difficult, however, to imagine how these negative electrons are maintained in their orbits. We seem to have an analogy to Saturn and its ring; the planetary object forms a conservative system; but it is difficult to form a mechanical idea of a system of electrons held in orbits about an atom. In the case of Saturn's ring there is not the multiplicity of actions which the circulating electrons exhibit, which are indicated by the lines in the spectra of elements: the iron spectrum, for instance, contains hundreds of lines which are supposed to be connected with the motion of electrons. The spectra of gases, also, consist of multitudes of bright lines which are arranged in a mysterious periodical order. These spectra are supposed to be due to a radiation of energy in which the negative electron is largely concerned. At present many physicists are attracted by a hypothesis of Bohr, who has modified Rutherford's hypothesis of the orbital circulation of the negative electron by the hypothesis that the orbits of the negative electrons increase and then return to their original configuration during a process of radiation of energy which is shown by spectral lines. When an atom is hit or receives energy from some outer source, the orbits of the negative electrons change. There is a great difficulty in conceiving how such a system can return to a condition of stability after it has been disturbed. The spectra of gases and the elements seem like the hieroglyphics on a still undeciphered tablet — a Rosetta stone. It seems certain that the discovery of the electron affords a clue.

In the study of atomic motions magnetism again comes to the front and shows that the spectral lines are due to the motion of electrons. When a discharge of electricity passes through a rarified gas contained in a glass tube placed between the poles of an electromagnet, a change in the position of the spectral lines of the gas is noted when the electromagnet is excited. This change is known to be due to the effect of magnetism on the orbits of the electrons.

It is interesting to compare the dimensions of the infinitesimal world with those of the stellar universe. In the electrical world we measure by means of electrons which will probably always be invisible to the human eye. Professor Milliken estimates that the size of the negative is to the size of the positive electron as a sphere two miles in radius is to the size of the earth. In astronomy we compare suns with suns, and estimate distances by what are called light years — the velocity of light, one hundred thousand miles a second, multiplied by the number of seconds in a year. Dimensions and distances in astronomical science are enormous in comparison with those in the atomic world. I quote the following from a paper of Professor Shapley, Director of Harvard College Observatory, on the size of globular clusters:

"The great cluster in Hercules, No. 13 in Messier's well known compilation of 103 nebulae and clusters, is the system chosen for the present illustration. To the unaided eye it is faintly visible as a hazy star . . . on a plate (photographic) of medium rapidity with an exposure of eleven hours; it records something like 30,000 stellar images brighter than the stars of twenty-first magnitude. . . . Even to those accustomed to think of the great depths of sidereal space, it is difficult to comprehend clearly the remoteness of the Hercules cluster. Its distance, 3.5×10^{17} kilometers (a kilometer is 3281 feet), is more than eight thousand times that of the nearest star now known. Light travelling with its hardly conceivable velocity of 300,000 kilometers (over 180,000 miles a second) in a second of time requires eight minutes for the passage from the sun to the earth, but it must travel more than two thousand million times as long to reach from this globular cluster. Hence our knowledge of the position and physical characteristics of Messier 13 does not refer to the system as it now exists. Our most recent information dates from the time the light we now receive left its remote origin in the cluster, and what has occurred there during the last 360 centuries is beyond our power of finding out. On the basis of our knowledge of the probable causes of these past conditions, we may believe with good reason that the cluster is now much as it was 36,000 years ago. Such an interval of time is of small consequence in the history of a gigantic stellar system; but while these pulses of light have been coming across the intervening fraction of unending space a thousand human generations have come and gone, man has emerged from a vague unrecorded past and in fleeting succession all his historically known national civilizations have slowly evolved, flourished in vaunted permanence and supremacy and quickly relapsed into oblivion or poor mediocrity. We recall, too, that of all the globular clusters whose radiation is continually streaming toward the earth, Messier 13 is one of the very nearest." The philosopher who follows the advances in electrical science cannot fail to reflect upon the insignificance of man in comparison with astronomical magnitudes; he may find an analogy to the size of himself in the relative size of the electron and the universe. Addison, in the century made memorable by Franklin's researches, writing on the wonders of creation, said: "As I was surveying the moon walking in her brightness, and taking her progress among the constellations, a thought rose in me which I believe very often perplexes and disturbs men of serious and contemplative natures. David himself fell into it in that reflection: 'When I consider the heavens the work of thy fingers, the moon and the stars which thou hast ordained, what is man that thou art mindful of him, and the son of man that thou regardest him?' In the same manner, when I consider that infinite host of stars or, to speak more philosophically, of suns which were then shining upon me, with those innumerable sets of planets or worlds which were moving round their respective suns — when I enlarged the idea, and supposed another heaven of suns and worlds rising still above this which we discovered, and these still enlightened by a superior firmament of luminaries which are planted at so great a distance that they may appear to the inhabitants of the former as the stars do to us — in short, while I pursued this thought, I could not but reflect on that little insignificant figure which I myself bore amidst the immensity of God's works."

If Addison had known of the wonders of the infinitesimal world he might have been lifted somewhat from his abasement of spirit by considering the possession of a mind in man, an object relatively as small as an electron which can control thunder bolts and send messages around the world.

CHAPTER XVI

RADIOACTIVITY

WE are now led to touch upon the most remarkable advance in electricity since the time of Franklin — the recognition of the electron, which has come to be treated under the title of radioactivity, but which merits the more comprehensive one of electroactivity. There has been a Franklin stage of electricity, a Faraday stage, and we now enter upon a more comprehensive one, in which all manifestations in electricity can be embraced under the one head — energy. This last stage of electrical science is the most difficult of comprehension of all the successive stages; for the mysteries of electricity are bound up with those of matter by thousands of phenomena, which in general cannot be seized by one who is not conversant with chemistry and molecular physics. This new stage of electricity received a great impetus by the discovery of the X-rays; for these rays led to the discovery of the electron. Physicists realized that a new world was opened to them; and keen attention was directed to the discharges of electricity in rarified air and gases. We truly can be said to have ascended from the region of lightning to that of the aurora. In order to welcome the electron into the family — so to speak — of electricity it was necessary to examine its credentials of electrical and magnetic effects. The discovery of the X-rays, I have said, was preceded by that of the cathode rays — the rays which emanate from the negative terminal of a discharge in a tube filled with rarified air. These rays, Crookes — their discoverer — supposed, were streams of radiant matter: they could be diverted by a magnet in their flight. They were next shown to be composed of negatively electrified particles by J. J. Thomson, who succeeded in repelling them by plates positively electrified. In the X-rays, where the electron exists in a higher state of exaltation than in the cathode rays, there is no evidence of an effect of magnetism. With the discovery of radium came still more complicated manifestations of electrons.

Before we enter into a circumstantial account of some of the steps that have led to the latest era in the subject of electricity it may be well to state in general terms the most significant results of the many researches which have founded the science of radioactivity. In the first place comes the discovery of the controlling influence of magnetism, mentioned above, upon the electron. Magnetism has again asserted itself in the electrical world. It has been proved that the mass of an electron is purely electrical, that is, it manifests itself as electricity in motion. Now it was proved by Maxwell, more than fifty years ago that an electrical charge in motion develops an electrical current, and therefore magnetic effects. This was shown to be experimentally true later by Rowland. An electron is not ordinary matter: one might say that it is an electrical essence. It is a singular fact that it increases in apparent mass as its velocity of movement becomes comparable with the velocity of light, and certain physicists are led to believe that all matter is electrical in nature. The electron in motion carries a magnetic nimbus — a magnetic field, as well as an electrical one.

It is an interesting fact that the presence of radioactivity was constantly about Franklin in his investigations, for it largely caused his difficulty in preventing leakage of electricity. All substances are more or less radioactive, and ionisation of air is always present. Frequently an accumulation of an electrical charge, on the other hand, is an obstacle to investigation. The glass cover of a compass becomes electrified by rubbing with a cloth; delicately suspended objects are prevented from swinging freely by attraction to neighboring objects. The operation of looms in mills is often obstructed by electricity developed by friction. Radium instantly dissipates these electrical charges by a process of ionisation which conducts away the electricity. Ultraviolet light does the same. Often in physics and chemistry an investigation of what seems only an error in calculations leads to an important discovery.

An electrical charge is not visible to the eye; it may be said to be only visible at the moment of its departure. We cannot see a charge on the surface of an electrified pith ball or on the surface of Franklin's plates or condensers, but at the instant of its dissipation it produces a crack in the glass of a condenser which in its zigzag course strongly resembles that of a stroke of lightning. But before the departure of an electric charge there are physical instruments which can detect the presence of the charge from its effect in producing a strain which results from the attraction of the positive and negative charges on the opposite sides of a glass condenser: a beam of light is sent through the glass of the condenser, or Leyden jar, at right angles to the electric strain; the beam of light is confined to one plane, or in scientific language, is polarised. Under the electrical strain the plane of the polarised beam is tipped and this shows the effect of the electrical strain. There is, however, no method, at present, by which one can see the charge on the surface of the charged body. It has no weight, it does not obstruct light, magnetism has no appreciable effect upon it. In liquids the ions are always attached to matter: there are indications that an ion in a liquid consists of an electrified part of the molecule of the dissolved salt with an attendant atmosphere of the solution around it.[1] The motion of ions in liquids always involves the movement of atoms or molecules (groups of atoms). An atom with an extra corpuscle is called a univalent negative ion; an atom with one corpuscle detached is a univalent positive ion. In gases the electrons sometimes travel alone: they can traverse space where there is no matter. The ions in gases must not be confounded with the ions in liquids; for the gaseous ion may be reduced to merely an electric charge — the electron. The atmosphere about us always has ions, some charged positively, some negatively; and an interchange of charges is always in action.

The corpuscle which is associated with the atom is what is termed the electron or the particle of electricity. The X-rays result from motion — either mechanical motion or chemical motion. They are now produced by radium through atomic motions. The science of radioactivity owes its name to the property of radium and many other substances emitting radiations which are similar to X-rays: they affect a photographic plate, produce burns, and ionise air and gases. While the generation of X-rays for purposes of surgery demands comparatively large apparatus and the exertion of considerable power, a salt spoon of radium shows to a lesser degree the peculiarities of the X-rays: bones of the human body can be photographed through the flesh; dreadful burns result from it. It is claimed that a spoonful of radium could kill all the inhabitants of Paris.

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[1] *Encyclopaedia Britannica.* Atoms.

The Curies obtained from about a ton of pitchblende — a grayish-black ore of uranium — an amount of radium which could be balanced on the thumb nail. Thus was made one of the greatest discoveries of modern physical science. Beside the X-ray properties of radium approx in reality $\frac{1}{30}$ it disclosed remarkable changes of matter: a gram of the substance (one ~~twenty-eig~~hth of an ounce) emits the enormous number 6.2×10^{10} (six and two-tenths times ten raised to the tenth power) per second of certain particles (called alpha particles). Nevertheless, the average life of radium is about 1800 years. Moreover, these expelled particles appear to be atoms of the gas, helium, so called from its presence in the sun. We seem to have here an evidence of the transmutation of metals into a gas — an intimation of alchemy.

The wonderful fact of the long life of radium activity leads one to think of the possibility that the earth once contained a large amount of this substance, and that, perhaps, the sun consists of it. If the earth, however, was originally composed of pure radium the amount in its crust today would not exhibit more activity than the amount of radium which can be obtained from pitchblende. I have said that it takes a ton of this substance to obtain a few grains of radium. Rutherford concludes that radium is being continuously produced in the earth, perhaps from the disintegration of uranium. In the process of the disintegration, and the successive changes which take place in the radioactive substances, enormous amounts of latent energy are set free. It is found that the total energy emitted from one gram ~~(one twenty-eighth of an ounce)~~ of radium during its changes is about one million times greater than any molecular change.

The geologists are led to reconsider their hypotheses in regard to the age of the earth, and the limit of the age of the sun. Lord Kelvin calculated that the sun had probably not illuminated the earth for 100,000,000 years and that it was almost certain that it had not done so for 500,000,000 years. He believed that it could not continue to light the earth for many million years longer unless there was a source unknown to us. This source may be radium. Already calculations on the earth's internal heat at various epochs have been shown to be doubtful, for it is probable that there is enough radioactive matter in the earth's crust to supply as much heat as is lost by radiation. It is computed that if the heat of the earth lost by radiation is compensated for by the energy set free from radioactive substances there are today 250 tons of radium in the earth's crust. The age of the earth during which it could support life is probably much longer than that assigned by Lord Kelvin.

I have used the term radioactive. All matter may exhibit in a much smaller degree the phenomena of radium, and hence may be called radioactive; not only is the earth a source of this activity but the atmosphere is also radioactive, and in this fact we see a possible connection between atmospheric electricity and radioactivity. Wires stretched in the air can collect a radioactivity which can be rubbed off and can produce to a very small degree the effects of radium. It is possible that there may be rayless emanations which although they cannot be detected by present methods of investigation may be present. Rutherford has shown that one of the particles of radium, the alpha particle, ceases to show the usual radioactive effects, such as phosphorescence and photographic effects after traversing two and a half inches in air; but it still possessed nearly forty per cent of its original velocity of projection. Since its ionisation and also its photographic effect ceased together, one is led to suspect that photography may be an ionisation effect.

Not only does radium contain what is termed the alpha particle but also the beta and gamma particles — designated by the Greek letters α, β, γ. The gamma rays are like the X-rays, and can produce all the effects of the latter rays — photographic effects and burns; they like the X-rays are not affected by a magnet; the beta rays are susceptible to magnetic effect. It was nearly three years after the discovery of radium that it was clearly seen what the characteristics of the alpha rays are; and from being the least considered of the rays, it now occupies, perhaps, the most important scientific position, for its rays have been identified as helium rays and, as I have already said, radium changes into helium gas — a most noteworthy fact! All the markedly radioactive substances have large atomic weights. It is a most puzzling fact that there are two kinds of the heavy metal lead, which cannot be distinguished from each other by chemical analysis, yet have different degrees of radioactivity. The theory is advanced that the atoms of radioactive substances suffer spontaneous disintegration, and that each disintegrated atom passes through a succession of well marked changes, accompanied in most cases by the emission of streams of helium atoms — alpha particles. The disintegration is explosive and the energy of motion comes from the freeing of the disintegrated atom. The expulsion, for instance, of the helium particle may leave the atomic structure unstable, and there is a new expulsion, and even successive ones after a period of time. The term metabolon has been suggested as a name for the condition of the changing atoms in successive disintegrations. It is thought that the metabolon has a definite structure and could be isolated if a sufficient quantity could be subjected to analysis.

Rutherford computes that, taking the velocity of a rifle bullet at 333 feet per second, the energy of the motion of the particle of electricity is 600,000,000 times that of the rifle ball. In this projection of bodies less than atomic size lies the principal cause of the heating effects of radium (due to the breaking up of atoms). The amount of energy due to this disintegration must be enormous; the total amount of energy given out by one gram of radium (one four hundred and fiftieth of a pound) during its changes is about one million times greater than any known molecular change.[1] If we could control the rate of this disintegration of radium and other radioactive matter, an enormous amount of energy could be obtained. Chemists have considered that temperature is the main effect in the breaking up of chemical compounds, or in the transformations of matter. The transformations, however, of radium are spontaneous and independent of temperature. Its emanations are not affected by chemical treatment.

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[1] Rutherford, *Radioactivity*.

Can we now picture to ourselves what the particle of electricity is? what relation it has to Franklin's one fluid theory of electricity? The electron, or particle of electricity is a corpuscle resident in arrangement of atoms, indeed is a part of every atom. I have said it is the smallest particle known to physicists. When this particle is torn from molecules and atoms, the electrical equilibrium of the atom is destroyed, a negative charge is taken from it; there remains the positive charge, and Franklin's theory of an excess and deficit is realized. This negative charge is the electron. When gases or vapors are subjected to the effect of X-rays or to radium and other radioactive substances these gases or vapors are said to be ionised, the negative particle appears, and, as we have seen, this negative particle or electron can be measured and weighed; but its former companion, the positive charge, once thought to be indissolubly connected with it, is not so well known. The negative particle plays a predominant rôle in the X-rays, in the effects of radium, and in wireless telegraphy and telephony.

At first most chemists were loth to believe that the atom was electrically divisible, but the fact is now generally received by them. The electron is apparently beyond the most delicate chemical analysis; yet, there are two varieties of lead which cannot be distinguished from each other by chemical analysis — one is radioactive, while the other is not. The radioactive one displays, although in a very feeble degree, the phenomena of radium; it can affect a photographic plate through opaque materials and can ionise.

CHAPTER XVII

ELECTRONS AND IONS

PROFESSOR J. J. Thomson who has been a leader in the development of the subject of radioactivity thus sums up his conclusions. "The atoms of the chemists must be still further divided, and must be conceived as made up of corpuscles. The mass of a corpuscle is the same as that of the negative ion in a gas at low pressure. In the normal atom this assemblage of corpuscles forms a system which is electrical and neutral. Though the individual corpuscles behave like negative ions, yet, when they are assembled in a neutral atom the negative effect is balanced by something which causes the space through which the corpuscles are spread to act as if it had a charge of positive electricity equal in amount to the sum of the negative charges or the corpuscles. I regard the electrification of a gas as due to the splitting up of some of the atoms of the gas, resulting in the detachment of a corpuscle from such atoms. The detached corpuscles behave like negative ions, each carrying a constant negative charge, which we shall call the negative charge, while the part of the atom left behind behaves like a positive ion with the units positively charged, but with a mass that is large compared with that of the negative ion. In the case of the ionisation of a gas by the X-rays or by uranium rays (radioactive rays) the evidence seems to be in favor of the view that not more than one corpuscle can be detached from any one atom. The ions in virtue of their negative charges act as nuclei around which drops of water condense when dust-free air is suddenly expanded."

C. T. R. Wilson, who it is said suggested the method of determining the size of the electron by using the X-rays to ionise suddenly expanded air, has shown that, by the use of the X-rays, it requires a greater expansion to produce a cloud in moist, dust-free air on positive ions than on negative ones, and he suggests that the moist atmosphere above us may through sunlight or the lightning flash, as well as by other means, become ionised. The negative ions attract moisture to themselves more readily than the positive: they grow to be larger drops and, descending to the earth with their negative charge, leave the atmosphere positive or neutral. The large drops of rain after a discharge of lightning may be an evidence of the ionisation produced by it. In fair weather the upper atmosphere is generally positive, and this fact gives color to Wilson's theory.

We thus see that the discovery of the electron is initiating us into the very heart of the mysteries of lightning. It has already done more than all other attempts to unravel them — the attempts in photography, statistical inquiries, etc.

In addition to the various rays emitted by radium which have been designated by the Greek letters, alpha, beta, gamma, there is a remarkable emanation which has been recognized as a gas like argon — the gas which is so remarkably inert — and which has a large atomic weight. "This emanation or gas is occluded by radioactive substances and gives forth rays which have not been clearly identified. These rays affect a photographic plate through opaque substances; they can be condensed by cold. The radiation is found to be material and to consist of streams of particles which are shot forth with great velocity. When the emanation is collected in a glass tube connected to an air pump, this tube is filled with a phosphorescent light which passes slowly through a capillary tube, and faster through a tube of larger diameter — while the pump operates. When the emanation is compressed, the phosphorescence increases. This emanation is 100,000 times as active as pure radium in those qualities which distinguish the latter, and, collected in glass tubes, it retains its properties for a long time. The emanation can be blown about by currents of air, and its motion can be traced by the luminosity it causes on a phosphorescent screen. Its particles seem to be continually breaking up and expelling alpha atoms — helium atoms — charged positively. After the emanation has radiated it is replaced by a new kind of matter which is deposited on the surface of bodies which gives rise to what is called excited activity.[1] This excited activity in turn is capable of ionising a gas — making it conducting for electricity — or affecting a photographic plate, but, unlike the radioactive substances from which it is derived, these properties decay more or less rapidly with time. This excited activity is caused by the deposition of some substance on the surface of bodies which can be dissolved off by acids, but when the acid solvent is evaporated the excited activity remains. The active deposit can be rubbed off with a cloth. It is found on a conductor, which is charged negatively. Elster and Geitel, who have largely increased our knowledge of radioactivity, ran a wire above the ground, about sixty feet in length, and charged it negatively. On rubbing the wire with a piece of leather moistened with ammonia, it was found to be strongly radioactive. This experiment showed that the emanation exists in the atmosphere; it was not deposited on bodies charged positively. Since the emanation is much affected by movements of air, the amount of excited activity on objects on the earth which have a negative charge is not so great. The direction of lightning strokes may be greatly influenced by it.

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[1] Rutherford, *Radioactivity*, p. 294.

The emanation in the air must come from the crust of the earth, and its amount in the air can give us some idea of the amount of radium in the earth. Rutherford estimates that if the emanation is distributed uniformly over the land portion of the globe, and extends to a height of five kilometers (somewhat over three miles), there must be about three million tons of radium in the surface of the earth: and, if it is uniformly distributed, a thickness of about forty feet would maintain the observed amount of this emanation in the atmosphere. The strong positive charge in the upper atmosphere must be due, not to emanations from the earth, but to ionising radiations from the sun. We see a clue to the fact that wireless messages are sent better by night than by day, and we see also a relation between violet rays of light and radioactive substances: the ultra-violet rays also ionise. Their burning effect is analogous to that of the X-rays and radium. These effects are largely confined to heights five miles above the surface of the earth. There they must be intense. The violet rays of the sun are greatly absorbed by the earth's atmosphere. Langley maintained that to an observer above our atmosphere the sun would appear strongly blue and violet.

"The ions formed in a space between two electrically charged plates travel with different velocities: the negative, in seeking the positive plate of the condenser, travels with a greater velocity than that of the positve ions in seeking the negative plate. The mass of the positive ion is much greater than that of the negative ion, and it requires a much stronger electric field to cause it to generate ions by collision than the negative ion requires. The size of the positive ion is atomic — perhaps the size of the hydrogen atom. Both the negative and positive ions carry an electric charge which is the same for both ions. This charge is that carried by the hydrogen ion in the formation of hydrogen and oxygen by the passage of an electric current through acidulated water. Positive electricity is always associated with bodies atomic in size, and never has a mass less than that of the hydrogen atom, while the mass of the negative ion (the electron) is one-thousandth that of the hydrogen atom at the low pressures under which it is formed. Much less is known in regard to the positive ion than in regard to the negative ion." [1]

We perceive that instead of the general term ion used by Faraday and the chemists, before the electrical charge was closely investigated, we now speak more specifically of ions as a combination of electrons and atoms.

The property of ions in forming nuclei of condensation is a very delicate method of detecting the presence of ions: a small quantity of radium held three feet away from a condensation chamber immediately produces a cloud of condensation. Violet rays of light also ionise rarified air. We have in the similar effects of X-rays, radium and violet light most important facts which are the basis of the great modern subject of radioactivity. Now, again, magnetism leads the way to further knowledge. A charged ion, moving with a velocity small compared with that of light, behaves like an electrical current. It can, therefore, be acted upon by a magnet. This effect is most noticeable on what are called the cathode rays, which are formed when electrical discharges pass through highly rarified air or gases; the rays emanate, as their name indicates, from the cathode terminal, and are directed away from the line of discharge. These rays have been found to consist of charged particles which move with great velocity, smaller however than that of the velocity of light. The cathode beam is extremely sensitive to the effect of a magnet. To show this sensitiveness it is usual to throw the beam upon a phosphorescent screen — such as one makes from salts of barium — where it forms a spot of light. This spot can be moved by a magnet, even when a comparatively feeble one is held at a distance of several feet from the beam. The cathode beam merges into the X-rays when the pressure of the air or gas in which the electrical discharges take place approaches that of a vacuum. The X-rays are not sensitive to magnetism.

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[1] Rutherford, *Radioactivity*.

It is well to bear in mind the probable relations of ionisation phenomena to electrical conditions in the atmosphere. When ionised air is blown through a metal tube, the tube gains a negative charge, while the air retains a positive charge. Can we suppose a current of ionised air to be driven between layers of clouds or between clouds and the earth? The northern lights are evidence of ionisation in rarified atmosphere, and their wavings show the influence of magnetism.

Franklin's question, "Is not the aurora borealis the flashing of electrical fire from positive to negative clouds, at a great distance, through the upper part of the atmosphere where the resistance is least?" can be definitely answered today in the affirmative; and much more information can be given. We recognize in the stupendous spectacle of the northern lights the play of the electrons under the control of the magnetism of the earth, and it may be of the sun. Is it not pathetic to picture to oneself the face of Franklin illuminated at night by the gleam of these lights while so much that would have enlightened his philosophical mind was concealed from him?

There may be other emanations which like the bacilli of certain diseases elude our tests and which remain to be discovered in the future. We cannot isolate ourselves from radioactivity. When radium has once been employed in a laboratory it is almost impossible to remove all trace of it.

Let us now dwell further upon the analogy between the effects of the X-rays and radium and those of ultraviolet light. Is the effect of this light due to its wave motion, or is it a corpuscular one? Is there any inkling in considering the corpuscular effect of a possible return to Sir Isaac Newton's theory of light — that it is due to the motion of corpuscles shot forth from the sun?

CHAPTER XVIII

LIGHT AND ELECTRICITY

HERTZ first showed the effect of light upon the electric spark. It is noteworthy that Franklin called attention to the influence of light upon electrical discharges and Professor Shuster remarks that if Franklin had used a clean piece of zinc, instead of rusty iron shot, he might have anticipated Hertz; for freshly cleaned metallic surfaces charged with electricity lose this charge when they are exposed to light. They acquire a positive charge if, without charge, they are insulated and are then exposed to light. It is significant, in regard to atmospheric electricity, that if a blast of wind is directed over a metallic plate thus conditioned, the magnitude of the positive charge is much increased. Is this true of the effect of the wind of a tornado over clouds?

If metallic surfaces are positively electrified there is a loss of charge when ultra-violet light falls on them. The effect of the violet light varies with the atomic weight of the metals used as surfaces, but not in exact proportion. Sunlight has the same effect as even invisible violet light but in much less degree. The photoelectric effect varies with the wave length of light, and with the degree of absorption of light by the substance which receives the light. Potassium is more sensitive to blue light than sodium; but the strong absorption of yellow light by sodium renders it more sensitive to blue light than potassium. Certain salts of the alkali metals exhibit this photo-electric effect in a remarkable manner: it is now employed in measuring the light of the stars, and it may have its use in wireless telephony.

The bearing of the photo-electric effect upon the present generally received wave theory of light — the theory which supposes that all energy, heat, light and electricity comes to us from the sun in waves — is of the utmost scientific interest; and I have intimated that we may return in a measure to Newton's corpuscular hypothesis which on the contrary supposes that the energy we receive is due to the impact of corpuscles. The failure of the wave theory to account for the photo-electric effect is thus stated by Professor Fleming: "A molecule cannot absorb more radiant energy than falls upon it." The cross section of a molecule is about 10^{-15} square centimeters. The liberation of an electron from a metal surface by ultra-violet light — the so-called photo-electric effect — requires an amount of work represented by 10^{-15} ergs (an erg is the unit of work). Hence light radiations would have to fall for 1000 seconds on each molecule to expel a single electron. The expulsion, however, takes place instantly: this fact seems to be inconsistent with the wave theory of light which supposes that the illumination is spread uniformly over the whole wave front. Two German physicists, Planck and Einstein, suppose a concentration of energy at points on this wave front—concentrations which Planck calls quanta of energy. Some writers suppose that the effect of light in setting off a store of energy is a trigger effect; a percussion cap can explode a powder magazine, and the energy necessary to pull the trigger bears no relation to the enormous amount of energy liberated. Ultra-violet light evidently relieves in some way the electrons from metallic surfaces, and these electrons leave the surfaces with great velocity and ionise the air or gas which they traverse by colliding with the atoms of the atmosphere. The velocity of the electron in leaving the metallic surfaces is not due entirely to the surface layer exposed to light, but it is modified by the inner layers of the metallic conductors removed by extremely small distances from the surface layers. The velocity, moreover, of the emitted corpuscle or electron depends upon the wave length of the illuminating light: it increases from the visible violet to the invisible violet, and it is extremely significant that the energy of the corpuscles emitted from metallic surfaces, receiving ultra-violet light or X-rays, is independent of the intensity of the incident light. This fact, that the energy of the released electron is independent of the illuminating light, raises momentous questions in regard to the generally received theory of light, the electromagnetic theory, which holds that light consists of electromagnetic waves propagated by means of the ether of space — an ether which is indefinitely elastic, without weight, and is continuous throughout space — pervading all matter. If we suppose that the energy of the liberated corpuscle or electron comes from the light, we must suppose that the electric forces of the electromagnetic wave which liberate the electron — since the energy of the electron is independent of the intensity of light — must also be independent of the intensity of light. Professor J. J. Thomson thus discusses this difficulty: "But this cannot be the case if, as usually assumed in the electro-magnetic theory, the wave front consists of a uniform distribution without structure; for in this case the magnitude of the electric force is proportional to the square root of the intensity. On the emission theory of light (Newton's corpuscular theory) a difficulty of this kind would not arise; for on that theory the energy of the luminiferous particle remains constant as the particle pursues its flight through space. Thus any process which a single particle is able to effect by virtue of its energy will be done just as well a thousand miles away from the source of light as at the source itself; though, of course, in a given space there will not be so many particles to do this process far from the source as there are close in. Thus if one of the particles when it struck against a piece of metal caused the ejection of a corpuscle with a given velocity, the velocity of emission would not depend on the intensity of light. There does not seem to be any reason for believing that the electro-magnetic theory is inconsistent with the idea that in this theory, as in the emission theory, the energy in the light wave, instead of being uniformly distributed through space may be concentrated in bundles which occupy only a small fraction of the volume traversed by the light, and that as the wave travels out the bundles get farther apart, the energy of each remaining undiminished. Some such view of the structure of light seems to be required to account for the fact that when a plate of metal is struck by a wave of ultra-violet light it would take years before the corpuscles emitted from the metal would be equal to the number of molecules on the surface of the plate; yet on the ordinary theory of light each one of these is without interruption exposed to the action of the light. . . . These considerations illustrate the evidence afforded by photo-electric effects on the nature of light; these effects may also have a deep significance with regard to the structure of matter. The fact that the energy of the individual corpuscles is independent of the intensity of the light might be explained by the hypothesis that the energy of the corpuscle does not come from the light but from the energy stored up in the molecules of the metals exposed to the light. We may suppose that under the action of the light some of the molecules are thrown into an unstable state and explode, ejecting corpuscles. The light in this case acts only as a trigger to liberate the energy of the atom, and it is this energy, and not that of the light which goes into the corpuscles."[1]

We have seen light used as a trigger to set off electric sparks (Chap. VII). In wireless telegraphy a comparatively minute ionisation of the air can act as a relay for feeble currents, and make it possible even to light up a room with wireless throbs from a source across the ocean. It may be that aeroplanes and submarines can be directed by electric currents set off by electromagnetic waves.

[1] *Encyclopaedia Britannica.*

CHAPTER XIX

PHOTO-ELECTRICITY

THE effect of ultra-violet rays upon electrical discharges has led observers to coördinate various phenomena which at first seemed isolated from each other. One of the most marked of these phenomena is that of selenium. This substance is non-metallic, and occupies a place between sulphur and tellurium. When a plate of it is interposed in a circuit of wire, which includes a detector — a galvanometer or telephone — a current of electricity is excited when light falls on the selenium. Alexander Graham Bell utilized this property for transmitting wireless signals by causing a rapidly interrupted beam of light to fall on such a plate enclosed in a circuit with a telephone. The light produced what is now called a photo-electric effect.

Immediately upon the discovery by Hertz of the phenomenon of the aid of ultra-violet light in facilitating electric discharges, a great impulse was given to the study of photo-electric effects. The loss of static negative charges, in many cases, was seen to be the effect of light. When the electron was discovered there was an immediate coördination of phenomena: the loss of negative charges could be explained by the escape of these electrons under the influence of ultra-violet light.

In general we know that photo-electric action results from the liberation of negative electrons from matter: this liberation is caused by ultra-violet light, and can therefore be called electromagnetic. The effect of light is also one of ionisation. We have seen that the X-rays immediately make a gas or vapor conducting when they strike a layer of these between two plates, one charged positively and the other negatively; the positively charged particles are driven to one plate, the negatively charged to the other plate, and these negative electrons convey an electric current. I have stated that the ionisation of gases and vapors appears to have an intimate bearing upon the striking fact that wireless messages are transmitted more readily at night than in the daytime. Marconi, in 1892, found that over long distances there was a marked difference in ease of transmission between day and night; he also found a difference between sunrise and sunset. This phenomenon is not clearly understood but it is believed to be connected with that of ionisation. "In the outer regions of the atmosphere there will be direct ionisation of the gases through the action of the extreme ultra-violet rays, and somewhat lower down there will be indirect ionisation due to the presence of dust particles which show photoelectric activity for longer wave lengths. There will also be the formation of condensation nuclei, such as drops of hydroperoxide formed from water vapor under the influence of ultra-violet light. These complicated effects produced in the atmosphere by sunlight (and also to a certain extent by cathode radiation from the sun) raise important and interesting questions in connection with meteorological phenomena and the propagation of electromagnetic waves around the earth.

"Eccles supposes that during the day the electric waves travel in a comparatively thin shell between the middle atmosphere and the surface of the earth, while at night they travel in the much wider shell below the high conducting layer postulated by Heavyside."[1] It is believed that the difference between day and night transmission of wireless messages may disappear by the employment of longer wave lengths of electricity.

The subject of photo-electricity is also embracing the phenomena of fluorescence and phosphorescence. Fluorescence is shown by a great variety of substances when submitted to light, the fluorescence of kerosene is a familiar example. Surgeons use screens coated with fluorescent salts to observe the effects of X-rays. It is found that these substances absorb certain wave lengths of light and transmit others of increased wave lengths. One could, therefore, immediately conclude that the wave lengths of the X-rays were shorter than those of fluorescent light. The name fluorescence was used by Stokes who observed its phenomena in the case of the mineral fluorite. Fluorescent light is of shorter duration than that of phosphorescence. The latter is shown by phosphorus — familiarly in sulphur matches — and is probably due to oxidisation. The reasons of its manifestation by lower forms of sea life are not clearly understood. The phosphorescence of the firefly is supposed to be due to an oxidisation of a substance secreted in certain organs of the firefly. Since all light is now regarded as an electromagnetic phenomenon, fluorescence and phosphorescence may be classed in the subject of photo-electricity.

It is natural also that, since the violet and ultra-violet rays are the most active rays in photography, we should suppose that the latent image is produced by the liberation of the negative electron. The electron in its movements may modify the relation of the atoms by a sort of catalytic action.

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[1] *Photo-Electricity.* Stanley Allen. Longmans, Green & Co., 1913.

In a letter to a correspondent, Cadwallader Colden, Franklin remarks, in regard to light, "I am not satisfied with the doctrine that supposes particles of matter called light, continually driven off from the sun's surface, with a swiftness so prodigious. Must not the smallest particle conceivable have with such a motion a force exceeding that of a twenty-four pounder discharged from a cannon? Must not the sun diminish exceedingly by such a waste of matter, and the planets, instead of drawing nearer to him, as some have feared, recede to greater distances through the lessened attraction? Yet these particles, with this amazing motion, will not drive before them, or remove the least and lightest dust they meet with. And the sun for aught we know continues of his ancient dimensions, and his attendants move in their ancient orbits.

"May not all the phenomena of light be more conveniently solved by supposing universal space filled with a subtle elastic fluid, which, when at rest, is not visible, but whose vibrations affect that fine sense in the eye as those of air do the grosser organs of the ear? We do not, in the case of sound, imagine that any sonorous particles are thrown off from a bell, for instance, and fly in straight lines to the ear; why must we believe that luminous particles leave the sun and proceed to the eye? Some diamonds, if rubbed, shine in the dark, without losing any part of their matter. I can make an electrical spark as big as the flame of a candle, much brighter, and therefore visible farther, yet this without fuel; and I am persuaded no part of the electric fluid flies off in such case to distant places, but all goes directly, and is to be found in the place to which I destine it. May not different degrees of the vibration of the above-mentioned universal medium occasion the appearances of different colors? I think the electric spark is always the same; yet I find that weaker and stronger sparks differ in apparent color—some white, blue, purple, red: the strongest white; weak ones red. Thus different degrees of vibration given to the air produce the seven different sounds in music, analogous to the seven colors, yet the medium, air, is the same.

"If the sun is not wasted by expense of light, I can easily conceive that he shall otherwise always retain the same quantity of matter; though we should suppose him made of sulphur constantly flaming. The action of fire only separates the particles of matter; it does not annihilate them. Water by heat raised in vapor, returns to the earth in rain; and if we could collect all the particles of burning matter that go off in smoke, perhaps they might, with the ashes, weigh as much as the body before it was fired; and if we could put them in the same position with regard to each other the mass would be the same as before, and might be burned over again. The chemists have analyzed sulphur, and find it composed in certain proportions of oil, salt, and earth; and, having by this analysis discovered those proportions, they can, of those ingredients, make sulphur. So we have only to suppose that parts of the sun's sulphur, separated by fire, rise in his atmosphere, and there being freed from the immediate action of the fire they collect into cloudy masses and, growing by degrees too heavy to be longer supported, they descend to the sun and are burnt over again."

This letter was written in 1752, little more than fifty years before Sir Thomas Young began his researches which established the undulatory theory of light — a theory now universally held. Franklin's conception of different vibrations of a subtle fluid strongly resembles the undulatory theory, if instead of vibrations, we read waves and instead of subtle fluid we substitute ether.

It is difficult, however, to conceive of the light of a candle by the employment of Franklin's reasoning on the cause of the sun's light. There is no falling back of the candle's product of combustion to serve for recuperation. The source of the light of the candle, apparently, must be sought in the breaking up of molecules and the release of atomic forces. There is nothing so fundamentally true in science as the fact that light consists of a wave motion; but how this wave motion starts in the case of any source of light is still a mystery, the solution of which seems to lie in a study of electrons; there is a possibility that their detachment and re-attachment to atoms may give rise to a pulsating wave motion.

CHAPTER XX

DIVERSITY OF ELECTRONIC ACTION

IT is noticeable that in our account of the infinitely small the negative particle of electricity has occupied the principal place: little has been said of a positive particle, but the term negative implies an opposite. The positive particle has been recognized. It is larger and more sluggish in its motions than the negative electron, but it is always atomic in size.[1] After the removal of the electron, the molecules retain a positive charge. Here we see a certain resemblance between the electron theory of electricity and Franklin's excess and deficit theory. The negative and positive ions move with different velocities: that of the negative is much greater than that of the positive.

Besides the manifestation of the rays, α, β, γ, from radium and similar manifestations in various degrees from a host of other substances, the mysterious gas emitted from radium especially, and also from other radioactive substances, appears to be directly transformed into an emanation, and this emanation goes through a series of other transformations which have been designated by the letters of the alphabet, A, B, C, D, E, F. Radium A gives forth only α rays (helium atoms). Radium A changes into radium B which gives forth β rays. B changes into radium C which gives forth more penetrating β rays than those of B. Radium C also gives out α rays and is the origin of γ rays.

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[1] Rutherford, *Radioactivity*, p. 294.

The α rays from radium C are very penetrating. There is also a residual activity consisting of three products, D, E, F. When a wire charged negatively is exposed to the radium emanation it is coated with radium A, B, C.

The emanation from bodies other than radium is highly interesting; for instance, the emanation from thorium goes through a series of changes which are also designated by the letters A, B, C, D. These successive products are continued in a long series. It is thought that thorium minerals may be a large source of a radioactive substance as valuable as radium.

It is surmised that there are also rayless products of radioactive substances. Certain of these substances break up without emitting any particles. There is probably a rearrangement in the atom. Since no particles are emitted the rayless product cannot be examined at present. The rayless products do not eject particles which are projected with so to speak the internal energy of the atom. In the case of the rayless products this internal energy is diverted into maintaining possibly a new arrangement in the structure of the atom.

An interesting feature of the ejection of a particle is the recoil — the kick back of the particle, like the recoil of a gun. By means of this recoil, actinium C can be obtained pure from actinium AB. Also radium B can be separated from radium A and C by the recoil method.

The emanations of radioactive substances open a vast field for inquiry. We have now concretely before us transformation of atoms. Not only do we have transformation of radium through a number of changes which have to be denoted by letters of the alphabet, but the successive emanations produce what is called induced activity in surrounding objects — walls of the containing vessel, or on any object submitted to the emanations. Rutherford has shown that the bodies made active by the emanation behaved as if a thin coating of very radioactive matter had been deposited upon them. This coating could be removed by rubbing or by dissolving it in strong acids. When the acid was removed by evaporation the active matter was left behind. These radioactive deposits are very complex in the case of many minerals. They are apparently not affected by chemical agents.

The emanations of radium behave like a gas. They can be occluded or released from combinations by heating. They can be stored, and be used in the treatment of superficial cancers. The successive changes in radium appear to stop, we have noted, with one variety of lead which is slightly radioactive, but has not yet been distinguished chemically from pure lead. Thus radium after manifesting diverse rays and recondite emanations dies in lead.

CHAPTER XXI

VELOCITY OF ELECTRONS

ONE is lost in consideration of the number of rays of varying properties that have been discovered in radium and other radioactive substances. We seem to have entered into a contemplation of a new sky with meteoric showers, planetary systems, and nebulous worlds. The main facts in regard to radium, the discovery of which has led largely to the opening of our knowledge of this universe of minute particles, are the immense energy of the radium particles which promises to be manifested through millions of years; the close resemblance of the photographic effect of the radium rays in general and that of their burning effect to the X-rays and the transmutation of the rays of radium into helium gas. Further investigation has shown the multitude of rays in radium and its congeners which have been designated by Greek letters: the number seems to be constantly increasing, and it is not to be expected that the unscientific reader can follow all the manifestations of these varied rays. It may suffice to call attention to the most marked phenomena exhibited by the α rays — phenomena which may be said to mark a new epoch in chemical and physical science. These rays — the α rays — fly from radium with a velocity of more than fifty thousand miles a second; their path can be traced by their impact upon certain phosphorescent screens; they produce scintillations of light when they strike these screens — sulphide of zinc screens for instance. The scintillations can be seen through a microscope by an eye made sensitive by a rest in darkness. Such a means of observation is provided by Crookes spinthariscope. In gazing through this simple instrument one seems to be looking at a milky way, which is brightening and dimming. The number of these scintillations can be obtained by a simple count; and the number which are intercepted by various substances — gases for instance — can thus be estimated. The amount of interception indicates the work done by the α particles — the amount of their energy consumed. We have thus a new method of physical analysis the elaboration of which is largely due to Rutherford, whom we have been compelled to quote so often in this new field of radioactivity. He has now proved that the α particles in flying through nitrogen and oxygen gases can separate hydrogen and perhaps other, hitherto unsuspected, gases from nitrogen and oxygen. At first it seemed that we were on the verge of discovery of veritable transmutation of elements. It is now held that the atom is an electrical structure composed of negative and positive particles held in equilibrium by electricity and magnetic forces. The atom is a charged nucleus surrounded at a distance by a distribution of electrons which make it electrically neutral. The nucleus is extremely small and the electrical region surrounding it is enormously large in comparison. The atom may be compared to the sun which represents the positive nucleus and the planets the negative electrons. Thus the electrical charge on the nucleus constitutes what the chemists have called the atom. Rutherford concludes that "All the chemical properties of an element are determined by the electrical charge on a nucleus much more than by its atomic weight. The electrical conception of what we have hitherto considered to be the entity of the atom explains the existence of atoms that do not differ in weight but have different properties, such as radioactive lead and non-radioactive lead — combinations which show no difference by chemical analysis.

The a rays penetrate into the nucleus of an atom by means of its swiftness and energy. This penetration is modified by the heaviness of the atom: it amounts to little in the case of such a heavy substance as uranium, but a light atom offers little resistance, and its nucleated structure can be broken up by the impact of the a particles. The disintegration produced by the a rays is minute. Rutherford computes that "not one in 10,000 of the a particles which pass through a nucleus come near enough to the nucleus of the atom to effect a disruption." We seem to have here an analogy from astronomy — the probable action of a shower of meteors in disrupting or breaking up some nebulous combination.

What an extension of the chemists idea of the atom! Rutherford remarks that Prout's hypothesis that all atoms are built up of hydrogen may yet be justified. The physical investigation of the a particles has thus opened a new field in chemistry; it has also greatly extended the conceptions in physical science. In both chemistry and physics our conception of size, velocity and time have been enormously changed. We have now entities which are one-thousandth the size of what was once supposed to be the smallest atom — that of hydrogen; we have velocities of particles approaching that of light — one hundred and eighty thousand miles a second. We have reason to conclude that the velocity of the α rays or that of any other ray which may be discovered can never exceed this velocity.

In the mind of the investigator of electron activities the atom with its electrons represents a sun, a positive charge surrounded by satellites. The stellar universe is on a large scale what a conglomeration of atoms is in any metal or earthly substance. This universe may represent an atom; the distant nebulae may be other atoms. Viewed from such a distant nebula, the collection of stars we see every night — the milky way — may seem a nebula; and the observations on the approach or recession of stars may find an analogy in the movement of electrons in the atom.

We think, however, of the satellites of our sun as material bodies, bodies having weight, possessing inertia; the mass of the negative electron has also been measured. Has it, however, mass in the commonly considered sense of something material. The flight of an electron is wonderfully different from that of a meteorite. The mass of the meteorite diminishes from the time it becomes visible until it imbeds itself in the earth. The electron increases in mass, steadily as its velocity increases. This apparent increase in mass is due to the electromagnetic effect it produces. The electron *per se* can be without mass; merely a point in space. From a physical point of view we seem to reach the philosophic conclusion that matter does not really exist: what appeals to us as matter is energy. "The famous experiment of the blows with a stick by which it was demonstrated to a sceptical philosopher that an outer world existed, only proves in reality the existence of energy and not that of matter. The stick, in itself, is inoffensive, as Professor Ostwald remarks, and it is its *vis viva*, its kinetic energy, which is painful to us; while if we possessed a speed equal to its own, moving in the same direction, it would no longer exist, so far as our sense of touch is concerned."[1]

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[1] *New Physics*, Poincare, p. 67.

CHAPTER XXII

WIRELESS TELEGRAPHY

THE discovery of the electron was followed by remarkable practical developments which were not entirely due to the discovery; but which were greatly stimulated by it.

This is true of the development of wireless telegraphy. The theory of the electron has explained the phenomenon, discovered by Edison, of discharge of electrical particles from the incandescent filament of an electric light which now is employed in the vacuum tube receiver of wireless telegraphy. The strength of wireless communications are constantly increasing, together with the sensitiveness of the vacuum tube receivers. Wireless telephonic speech can now be instituted between aeroplanes and the earth. An aerial wire is suspended from the aeroplane — the body of the aeroplane serving as the earth.

The great war has stimulated practical electrical research to a remarkable degree. It has superseded what at one time seemed well established magnetic and electrical methods by new ones which at first sight seemed to have a remote resemblance to former appliances. For instance, we have noted that the electric spark which before the war was employed to send wireless messages has now, we have said, been largely replaced by vacuum tubes containing an incandescent filament.

The electric spark method of sending wireless messages did not allow of telephonic wireless messages:

human speech could not be transmitted. Now this has been made possible by the use of the vacuum tube. At one time the mirror galvanometer seemed to be the most delicate detector of electrical currents. It revealed their existence to the eye. This organ became the principal instrument of electrical research, now the telephone and the ear have taken the place of the galvanometer and the eye. The telephone is relied upon entirely in wireless telegraphy.

The preceding chapters in this treatise were largely occupied with the behavior of the electric spark in its manifestation of lightning and its oscillations. The discussions in these chapters have ceased to have practical bearings; they are to be regarded chiefly from a purely scientific side which however has led to the greatest practical development of electricity in modern times, that of wireless telegraphy.

While electrical methods have thus received great development there has been marked abandonment of some of them in practical life for mechanical methods. For instance, the magnetic compass has largely given way to the gyroscopic compass. Lord Kelvin devoted much thought to the perfection of a marine compass which was thought to be the last word in the method of using magnetic needles for the direction of ships; and his refined instrument replaced the comparatively sluggish and cumbrous compass of generations of mariners. Now the gyroscope, which together with a top formerly served professors to illustrate the laws of motion to students, has supplanted the magnetic compass on large iron ships. The explanation of the action of the gyroscope rarely penetrates into the minds of the professors' listeners, and I therefore limit myself here to the statement that the compass-like directing action of the gyroscope depends upon the principle that the plane of a rapidly rotating disk tends to preserve its direction, notwithstanding the rotation of the earth. Some of my readers doubtless have seen the pendulum in the Pantheon at Paris, which in its swinging marks a line on sand spread beneath its knob. This line preserves its direction, notwithstanding the rotation of the earth. The installation of the pendulum in the Pantheon is a tribute to Foucault who discovered the law of the gyroscope. By means of this law a line can be established which is entirely independent of magnetic perturbations due to changes of position of the north and south poles of the earth, or those due to the iron or steel of ships. The ships' courses can be set with the greatest accuracy by means of the invariable direction of the gyroscopic plane. It is said that steamers equipped with the gyroscopic compass save much time and therefore coal; it is necessarily used on submarines and on dreadnaughts where the mass of iron prevents the use of the magnetic compass. The rotation of the gyroscopic plane, however, is accomplished by means of an electric motor, and it may be said that magnetism still has a controlling power in navigation.

I have spoken of the displacement of the direct electric current in favor of the alternating electric current. The use of the latter constantly increases. The use of the oscillations of the electric spark in wireless telegraphy is an example of the employment of electric oscillations untrammeled by mechanical devices. We are witnessing now an interesting departure from the use of the very rapid oscillations of the electric spark; sound waves modify the movement of electrons in the vacuum tubes employed in wireless telegraphy. The recent war greatly developed methods of undersea communication. During the last year of the war the enemy's submarines were so anxious to avoid detection of their position by hydrophones — applications of microphones — that they had no time for attack, and pursued tortuous courses, in the endeavor to escape. When the history of the part that science played in the war is written the achievements of the band of professors gathered at New London in the application of electricity to the problem of undersea detection of submarines will make a notable chapter.

The measurements relating to the size and movements of the electron do not seem at first sight to have practical bearings. We must, however, bear in mind the already acknowledged importance of the study of the electron in the improvement of wireless telegraphy and telephony. Perhaps we can look forward to a release of atomic energy by a closer study of electrical conditions. It is calculated that a pound of coal contains more hidden energy than is at present obtained from one hundred and fifty tons of it.

CHAPTER XXIII

ELECTRONS AND VIOLET LIGHT

THIS treatise began with a description of the phenomena of lightning, and one may now ask — after our discussion of the present theory of the particle of electricity, the electron — what have we learned about lightning?

I cannot do better than to quote Sir J. Lamor. In a paper delivered before the British Association in 1914, he said:

"The rationale of electric discharge in a gas (he must have also included air) is now understood. When a small region becomes conducting through ionisation by collision in the electric field, it should spread in the direction in which the field is most intense, which is along the lines of force. Thus the electric rupture is not a tear along a surface, but a perforation along a line. This is roughly the line of force of the field. The electro-kinetic force induced by the charge, being parallel to the current, does not modify this conclusion. A zigzag discharge would thus consist of independent flashes, the first one upsetting adjacent equilibrium by transference of charge; successive discharges between the same masses would tend to follow the same ionised path, which may be meantime displaced by air currents.

"If the line of discharge is thus determined by the previous electric field, the influence of a lightning conductor in drawing the discharge must be determined by the modification of this electric field which its presence produces; for in a field of vertical force, such as an overhead cloud would produce, it may be shown that the disturbance caused by a thin vertical rod is confined to its own immediate neighborhood. Thus, while it produces a strong silent discharge from earth into the air, it does not assist in drawing a disruptive discharge from above except in so far as the stream of electrified air rising from it may provide a path. It is the broader building, to which the rod is attached, that draws the lightning: the rod affords a means of safely carrying it away, and thus should be well connected with all metallic channels on the building as well as with the earth. It is the branching top of an isolated tree that attracts the discharge; a wire pole could not do so to a sensible degree. Separate rods projecting upward from the corners of a building do not much affect the field above it; but if they are connected at their summits (or their bases, probably Lamor would agree) by horizontal wires, the latter, being earthed, lift up the electric field from the top of the building itself to the region above it and thus take the discharge which they help in attracting, instead of the building below them. Similarly when the lines of force are oblique to a vertical rod its presence does somewhat modify the field and protect the lee side; but generally the presence of a rod should not ever be a source of danger unless the ionised air rising from it provides an actual path for discharge."

These conclusions of a distinguished investigator of the electron theory confirm, it will be seen, the method of protection adopted for the physical laboratory of Harvard University (Chap. III). In summing up the progress of our knowledge of lightning, it appears that it is condensation and not evaporation which appears to be the important factor in producing electrical effects in the atmosphere. Dust particles are nuclei for condensation. A fall of temperature accompanied by condensation is favorable for the display of northern lights — the lightning so to speak in the upper atmosphere. But evaporation is incidently favorable for the production of thunder storms: on account of the greater heat of spring and summer over that of autumn and winter the results of evaporation can rise to greater heights, and the upper clouds can collect a large amount of positive electricity which is always present at even moderate heights. Since the earth is always negative, there is a tendency in lightning to strike to the earth.

One might imagine a supply of negative electrons on the outer limits of the earth's atmosphere kept up perhaps from the sun (an ionisation by ultra-violet light) which may be kept from dissipation by conduction to lower limits by dry air. This electric charge could act inductively upon moist strata of air nearer the earth. Thus a negative charge on the outer limit of the atmosphere might induce a positive charge on the clouds that arise by evaporation in spring and early summer. The fact that thunder storms occur more frequently in spring and early summer than in autumn and winter lends some color to the above hypothesis that there may be a reservoir of electricity on the limits of our atmosphere, fed by the sun. Franklin seemed to have entertained this supposition, for he remarks: "Who knows but there may be as the ancients thought, a region of fire above our atmosphere, prevented by our air and its own too great distances for attractions, from joining our earth. Perhaps the aurora borealis is a current of this fluid in its own region, above our atmosphere, becoming from their motion visible." If we substitute for the conception of a region of fire or of mysterious fluid the idea of electrons we see that Franklin, just as in his excess and deficit theory of electricity, touched very closely a modern theory.

In order to understand the progress of our knowledge of electricity since the time of Franklin we must study the ionisation or separation of matter into positive and negative particles by means of the shortest waves of light. The remark of C. R. T. Wilson, that sunlight may have an ionisation effect on atmospheric electricity, is significant in reference to the fact that wireless messages are less disturbed at night than in the daytime. This fact is an important one from a practical point of view and is still more significant from its scientific bearing. Why should the electric waves of the wireless message be affected by an ionisation of the air.

The fact that ultra-violet light acts in a subdued way like the Röntgen rays and radium in ionising air would, I think, be seized upon by Sir Isaac Newton as a support of his corpuscular theory, if he were alive and still unconvinced that light is transmitted by waves through a universal ether — an infinitely elastic medium of no weight and of no structure.

Is the effect, therefore, of the violet light a corpuscular one? Let us dwell further upon the ionising effect of violet light. We have seen that freshly cleaned metal surfaces charged with electricity lose this charge when exposed to ultra-violet light; they acquire a positive charge if, without charge, they are insulated and are exposed to this light. It is significant in regard to atmospheric electricity that if a blast of wind is directed over a metallic plate, thus conditioned, the magnitude of the positive charge is much increased. Is this true of the wind of a tornado over positively charged conducting clouds?

If the metallic surfaces are positively electrified there is no loss of electricity when ultra-violet light falls on the plate. The effect of the ultra-violet light varies with the atomic weight of the metals employed as surfaces, but not in full proportion. Sunlight has the same effect as violet light but in much less degree. The effect varies with wave lengths of sunlight, and with the degree of absorption of the light by the substance which receives the light.

Up to this time we have caused an electric current to pass from one charged plate of an air condenser to another by ionising the intervening air by X-rays, or putting a layer of radium or other radioactive substance on one of the opposed surfaces of the condenser. Now we see that if ultra-violet light falls on one of the opposed plates of such a charged condenser there is an ionising effect and an electric current results. Ultra-violet light evidently relieves in some way the electrons from conductors of electricity — metallic surfaces — and these electrons leave the surfaces with a great velocity and ionise the air or gas which they traverse. There are four ways in which the electrons make themselves evident: one by means of the X-rays, one by radium, one by discharges of electricity in rarified gases, or discharges from a wire heated by an electric current into a vacuum, and one by light. Their action in the electric current on conductors is only surmised; it is recognized that they whirl around in the space near magnetic poles

— around lines of magnetic force. While we can trace their orbits in rarified media, we are at a loss to conceive of their orbits in or around atoms which are compressed together in the ordinary state of matter. Thus we have gone farther in the direction of the vacuum which extends between us and the highest limits of the matter of the sun than we have in the direction of great compression of matter — that toward the centre of the earth.

It seems that every material atom can be dissociated and be made to yield a particle smaller than itself. Matter is always decomposing. Some believe that radium borrows its energy from the surrounding medium: that it is a species of transformer of the electromagnetic waves which convey to the earth energy from the sun. Others believe that the energy manifested in radium is the result only of atomic disintegration. Professors Elster and Geitel lowered a certain quantity of radium to a depth of half a mile below the surface of the earth and in a region where it was surrounded by pitchblende could not perceive any diminution of intensity. One would suppose that the radium in the pitchblende would absorb the energy in the surrounding medium so that less would reach the certain quantity of radium.

Poincare in his *New Physics* asks, "Whether we are not, for the first time, in the presence of a transformation of gravitational energy. It may be singular, but it is not absurd, to suppose that the unit of mass of radium is not attracted to the earth with the same intensity as an inert body. M. Sagnac has commenced some experiments, as yet unpublished, in order to study the laws of the fall of a fragment of radium. They are necessarily very delicate, and the energetic and ingenious physicist has not yet succeeded in finishing them. Let us suppose that he succeeds in demonstrating that the intensity of gravity is less for radium than for platinum or the copper of which the pendulums used to demonstrate the laws of Newton are generally made; it would then be possible still to think that the laws of universal attraction are perfectly exact as regards the stars, and that ponderability is really a particular case of universal attraction, while in the case of radioactive bodies part of the gravitational energy is transformed in the course of its evolution and appears in the form of active radiation."

Mathematical physicists have endeavored to include gravitation in electromagnetic theories. Lorentz, who has carried such theories farther, perhaps, than any physicist since Clerk Maxwell, sought to explain gravitation by a relation between the pressures which might arise on bodies by vibratory movements of rapidly moving electrons. "M. Sutherland has imagined that attraction is due to the difference of action in the convection currents produced by the positive and negative corpuscles which constitute the atoms of the stars, and are carried along by the astronomical motions. But these hypotheses remain rather vague, and many authors think, like M. Langevin, that gravitation must result from some mode of activity of the ether totally different from the electromagnetic mode."[1]

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[1] *New Physics*, Poincare.

CHAPTER XXIV

THE EXTENT OF NEW VIEWS

IT will be seen from this short résumé of the advance of our knowledge of the infinitesimal world how far we have advanced from the comparatively simple subject of the molecular theory of gases in the space of twenty years. In this theory we were concerned with the collisions of molecules and their activity under the stimulus of heat: their paths in the main were along straight lines, and these paths were not influenced by magnetism. The mathematical analysis involved was simple compared with that needed in the discussions of electrotonic movements which now puzzles the students. William James, the philosopher, once said to me with a sigh, "I suppose a simple truth will come from the array of symbols which, in time, we can all seize." It is true that the simple explanation is always the final one in physical science; and we now await it.

Tyndall in his address before the British Association, in 1874, quoted the Italian philosopher, Giodano Bruno, thus: "Matter is not the mere naked empty capacity which philosophers have pictured her to be, but the universal mother who brings forth all things as the fruit of her womb." Tyndall drew upon himself much criticism at the time by his apparent assent to the materialism thus expressed, and by his remark that we may yet discern in matter "the promise and potency of all terrestrial life." If Tyndall were living today would he substitute for the word matter, that of electricity? For it has been shown that the electron in its extreme flight increases in mass: we therefore have what is termed electric inertia. Now inertia is a universal property of matter, and our views of what we call matter seem destined to be greatly extended. Must there not be some other manifestation, not electrical, which controls the formation of electrical force which we call matter? Is this other manifestation gravitation? Does the latter and its general law of the attraction between all particles of matter control centers of force; or is gravitation itself a manifestation of electromagnetism? If all matter is electrical how should we regard Franklin's theory of excess and deficit electricity, which is so like the modern electron theory. Both theories hold that when matter is electrically neutral — that is, does not exhibit either a positive or a negative charge — the negative electron holds the positive particle in a state of equilibrium. When by some mechanical or chemical exhibition of energy the negative particle is driven away from the positive, a deficit is created and there seems to be an excess of positive electricity, which causes, so to speak, a rush after the vagrant negative particle, and when they meet there is a lightning discharge, and there is a renewal of the state of electrical equilibrium. Frictional electricity, which was the only means of producing electrical effects open to Franklin, is now recognized as due to mechanical relations between matter and electrons. From different relations, due to structure of matter, he conceived of the positive electricity which arose from rubbing glass and the negative which came from stroking resin — vitreous and resinous electricity. Franklin, in having a clear idea of a state of deficit and excess, to which we have constantly drawn nearer, could not give a clear notion of the attraction of two positively charged pith balls or that of two negatively charged ones. It was only after the discovery of the electric current that the great agency magnetism or, in scientific language, electromagnetism, came to far outshadow the effects of frictional electricity and to open a fruitful ground of conjecture in regard to attraction or repulsion of electrical charges, and the attraction or repulsion of magnets. We now recognize that there is a whirling about lines of magnetic force. Manifestations of light due to the motion of electrons are influenced by magnetism: color is dependent upon the orbital speed of electrons about atoms, or what might be called electrical centers.

The researches in physical science during the last twenty years have greatly extended our conceptions of matter and of velocities. But what shall we say of our conceptions of time? Darwin in his *Origin of Species* speaks of the inability of man to comprehend the lapse of it, and draws attention to the wearing down of the chalk cliffs on the English coast. He concludes that for a cliff five hundred feet in height, a denudation of one inch per century (for the whole coast under consideration) would be an ample allowance. At this rate the denudation of Weald would have taken 300,000,000 of years. In comparison with the time involved in forming a geological sediment, how short is the age of the oldest man! It is of an order of infinitesimals beyond conception. The new doctrine of relativity is distinguished by its analysis of the element of time; according to Einstein, the propounder of the doctrine, all our measurements are relative. He believes that the great mathematical physicists of the past and present, Maxwell, Lord Kelvin, and Lorentz, could have deduced their results by the theory of relativity without the use of complicated mathematical analysis, much as quaternions and vector analysis shorten physical computations. While the imagination of the scientific man is greatly excited by the discovery of the electron and its activities, it is perhaps natural that the literary man and the metaphysician should think of an influence like magnetism between one person and another. There is, however, this striking difference between the imagination of a trained scientific man and that of a purely literary man. The imagination of the scientific man is based upon the study of facts while that of the literary man ranges without such limitation. The following is an example of the effect of modern developments of electricity upon the latter type of mind.

"It will not, I imagine, be too daring to hope that there are other beings more or less intelligent; but an intelligence scattered, general — a sort of universal fluid which penetrates diversely, according to whether there are good or bad conductors of spirit in the organisms which they encounter. The man will be, up to this time, upon the earth, the mode of life which offers the least resistance to this fluid which the religionist calls divine. Our nerves will be the wires on which this fluid, more subtle than electricity, penetrates. The circumvolutions of our brain serve in some sort the bobbins of induction where the force of the current multiplies itself; but the current will not be of another nature; will not come from any other source from that which passes into the stones; into the star; into the flowers or the animals."[1]

The results of the investigation into the activity of the electron tend to make the scientific man more tolerant of such intimations as those we quote. Carlyle in his essay on the signs of the times inveighs against the increasing tendency to a mechanical view of life: many would agree with him in his lament and would term the present age, the machine age. But what a range the spirit of the scientific man now takes? "He has given to airy nothings a habitation, and a name." He discovers that these airy nothings have planetary motions comparable to these motions in velocity. He has opened a new field in chemistry; and even the physiologist is strengthened in the belief that there are bacilli which can pass through the closest textured diaphragm known to medical science. There is a tendency today to regard all the manifestations of energy as electromagnetic, a tendency to give up ideas of an ether, much as we have given up all fluid theories.

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[1] Maeterlinck, *L'Intelligence des Fleurs*, p. 103, Chap. XXX.

The advance in scientific thought, stimulated by the discoveries in electricity since the time of Franklin, has been even greater than the advance in the practical employments of electromagnetism. We have seen a grouping together of what were considered only sixty years ago, as separate manifestations of light, heat and electricity. These are now considered under the one head, energy. Franklin's unifying thoughts in politics and religion seem to have reached forward in the development of his favorite subject of inquiry. The development of electricity has made chemistry and physics one subject, and has even modified the views of biologists, some of whom see in the activities of the electron the beginning of the evolution of life. This is the greatest problem of all time. How did life originate on the earth after it had cooled from a state of heat in which it is supposed that no life could exist? It has been supposed that the earth in passing through space entered at one time into a region of germs of life. Now there is a tendency to believe that there has been what may be called an alchemy of life on the globe itself. When vapor was formed the electrons of the vapor and the colloidal state of metals originated organic matter, and therefore life. This theory has not yet received any experimental proof. The character of Franklin's philosophical mind was well illustrated by his endeavor to bring lightning to earth where one could study it in embryo. It cannot be said of his thoughts on electricity that they were utilitarian, as it has been said of most of his thinking; yet even his scientific work, which did not seem, even to him, to have any practical bearing, has been a link in the chain of the great utilitarian advance in his favorite subject — electricity. His mind was not led away to the field of invention which has proved so fascinating to electricians, and could rest on broad philosophical views of the field in which he worked. I imagine that if he were to come on the earth today he would be more interested in the philosophy of physics than in practical employments of it: his mind had philosophical breadth. He would behold the entrance of electricity into the field of chemistry, and the establishment of his philosophical theory of attraction and repulsion; he would perceive the influence of the advance of electricity upon philosophical thought.

We can judge from the exhibition he has given of judicial thought in science what would be his opinion on the supposed attraction or repulsion of human minds of persons separated by great distance — in other words on telepathy. From my study of the character of his thinking, I conceive of his agreeing to the following chapter on telepathy.

CHAPTER XXV

TELEPATHY

THE surprising advances in electrical science have had great influence upon contemporaneous thought. The discovery of the electron has modified our views of chemical science, geological science, and mental philosophy. There is no subject which has excited the human mind more in this generation than that of electricity. Philosophers seek to adjust their ideas to the new views of the constitution of matter; and the seeker after marvels, stimulated by the discovery of the telephone and of wireless telegraphy, sees still greater possibilities in the future. Among these possibilities is that of telepathy: even some scientific men think that telepathy is the next great step in the communication of intelligence. Furthermore, some believe that it is already in the possession of mankind. Sir Oliver Lodge remarks in his treatise on the survival of man: "Tell a secret to A in New Zealand and discover that B in St. Petersburg is, before long, aware of it, neither having travelled, how can this happen? The distance between England and India is no barrier to the sympathetic communication of intelligence in some way of which we are at present ignorant: that just as a signalling key in London causes a telegraphic instrument to respond instantaneously in Teheran — which is an everyday occurrence — so the danger or death of a distant child, or brother, or husband, may be signalled without wire or clerk to the heart of a human being fitted to be the recipient of such a message.... What is the medium of communication? Is it through the air, like the tuning fork, or through the ether like the magnets, or is it something non-physical and metaphysical? . . . The fact of telepathy having been experimentally established (*sic* he goes on with more analogies) physical sensations, light, sound, etc., can be transmitted. Now then I say, shut the eyes, stop the ears, transmit no material substance, interpose distance sufficient to stop all pulling and pushing, can thought or ideas be transmitted? Experiment answers the question: they can. But what is the medium, and how does the process occur? It remains for further investigation to ascertain." Analogies from electricity in favor of telepathy appear to me to be very misleading. The apparatus for telegraphing over great distances requires for its functioning a considerable amount of energy — a large number of batteries, or a dynamo. This is also true in regard to telephony and wireless telegraphy. To transmit wireless messages from Persia to London would require a plant of several horse power. If a brain storm of an impassioned orator in Teheran should ever affect the brain of a person in London it would have to be transmitted by a medium of which we have no conceptions.

It may be well to consider the subject of false analogies. Mill in his treatise on logic thus speaks of their fallacies: "Because a just analogy has been discerned between the metropolis of a country and the heart of the animal body it has sometimes been contended that its increased size is a disease — that it may impede some of its more important functions, or even be the cause of its dissolution.

"Another example is the not uncommon dictum that bodies politic have youth, maturity, old age, and death, like bodies natural; that after a certain duration of prosperity they tend spontaneously to decay. This also is a false analogy, because the decay of the vital powers in an animate body can be distinctly traced to the natural progress of those very changes of structure which, in their earlier stages, constitute its growth to maturity; while in the body politic the progress of those changes can not generally speaking have any effect but the still further continuance of growth: it is the stoppage of progress, and the commencement of retrogression that alone would constitute decay. Bodies politic die, but it is of disease or violent death; they have no old age.

"A false analogy has been made the basis of an argument in favor of despotic government. It has been likened to the government exercised by a father over his children, a government which it resembles only in its irresponsibility, that is, in the fact that it is a despotism; whereas the beneficial working of paternal government depends, when real, not on its irresponsibility, but on two other circumstances of the case — the affection of the parent for the children and the superiority of the parent in wisdom and experience. The argument from this false analogy is usually summed up in the convenient phrase 'paternal government,' — the fallacy lurking in the word 'paternal,' a word which may refer to the power of a father or to his power judiciously exercised; it may mean like a father or like a good and wise father."[1]

Besides the false use of analogies by those who see in the marvels of magnetism and electricity an assurance of telepathy, there is a fondness for exaggeration: a story of what seems to be unusual grows with its repetition. Psychology replaces physics. One is often reminded in hearing an account of telepathic or what are regarded as spiritualistic communications of the stories of children, who after returning from a reported haunted wood clothe their memory of a distorted tree trunk with garments, and give it movement and speech. Such credulity often is manifested in second childhood.

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[1] *Principles of Rhetoric,* Adam S. Hill, in quoting Mill.

The facts of radioactivity are so wonderful and unexpected in the subject of electricity that one is led to surmise on the possible existence of other subtle manifestations of energy. Many are ready to believe that we shall yet find influences — I will call the emanations from one human brain to another an influence — which are made to serve in telepathy.

The attraction between magnets is the easily seized analogy to the often observed attractions between human beings, an attraction which is believed to be not that of sex or visible personal charm. There is a fixed belief in what is called animal magnetism but this has never been observed between two persons blindfolded, deafened, and placed in a completely darkened room beyond each other's touch. This it seems should be the first experiment to be tried by psychologists who have telepathic leanings. It may be argued that such secluded individuals cannot yet recognize or their observers cannot measure some subtle influence between human brains which remains to be discovered in the future.

Physiologists have discovered that an electric condition exists in human nerves and muscles; this condition disappears when the nerves and muscles die. An electric current flows from the heart through joined hands of an individual: electric currents in any net work of conductors can excite, by induction, currents in neighboring conductors. In the case of the human individual these currents of induction are extremely feeble. Any evidence that some people are more electrical, so to speak, than others, is not warranted by facts: the electrical effects observed are due to the friction of clothes or shoes on dry materials. Also nothing magnetic pertains to the human organism. Several times in the history of human delusions, theories of animal magnetism have had vogue. An extraordinary account of the influence of magnets on human beings was published by Baron von Reichenbach in 1848: patients not only felt bodily sensations after being stroked with strong magnets but saw luminous appearances emanating from the magnets. The particularisations are very minute; and it seems on first reading of the somewhat voluminous treatise of Reichenbach, which reached a very credulous public seventy years ago, stimulated by the adherence to Reichenbach's views of even notable physicians, that in common parlance, there must have been something in what the German called Odic force. It was not long before properly trained observers proved that pieces of wood painted like the magnets which were used could produce all the effects attributed to magnetic influences. The luminous effects were hallucinations. No healthy-minded observer today feels the slightest sensation in placing his hand in the most intense magnetic field that the water power of Niagara Falls can produce.

Still it is a striking fact that so many of man's aspirations have been fulfilled. The transmission of intelligence over vast distances was once only a dream; so was flying; so was the disappearance of horses in traffic; man has visions of telepathy. Will they be realized, and will electricity and magnetism partake in this realization? It is not strange that Bergson the philosopher, supported by eminent physicists, states in his recent writings that telepathy is an acknowledged fact. The philosophers, in general, accept what most physicists believe is a fantasy of some of their co-workers' minds, while at the same time they — the philosophers — are becoming very critical of what have been long held as truths in physical science.

CHAPTER XXVI

ELECTRONS AND THE X-RAYS

THE philosophers — not the physical philosophers — claim that the advances in electrical science have carried the physicists into a metaphysical study of what had been thought fundamental and absolute. One of the foundations of electromagnetic theory — that of the existence of an ether of space — has seemed to crumble: no physicist has been able to prove its existence, except in the mind's eye. What are called absolute measurements in electricity — measurements upon which all our practical employments of that agency are based — are no longer deemed absolute. The doctrine of relativity teaches that there is no fixed point in space: that all measurements are therefore relative; no two events are simultaneous; we have been led to believe that our universe was moving toward the constellation of Hercules; there is just as good reason to suppose it moving in the opposite direction; the shortest distance between two points may be the longest distance. The ultimate postulates of mathematicians and physicists are in as much doubt as those of metaphysics: the element of time has been left out of calculations. With the three dimensions by which we have hitherto measured bodies — length, breadth, and thickness — there is another dimension, that of time; for the object we visualize is moving during our measurements. The element of time, therefore, must be considered when motion is taken into consideration. Lorentz of Leyden has deduced from electromagnetic theory that the electron takes an ellipsoidal shape — like that of an egg — in rectilinear motion when its shortest axis lies in the direction of the motion. Thus electrical theory supports the supposition of Fitzgerald, the physicist, that matter contracts in this direction. It is computed that the diameter of the earth contracts an inch in its path about the sun. The doctrine of relativity rests largely upon this contraction hypothesis and upon the undoubted fact that in all problems of motion we must take into consideration a fourth dimension — that of time.

While the philosophers of the metaphysical school are gratified that physicists seem to be joining their ranks, the classicists compare our present atomic and electrotonic theories with that enunciated by Lucretius, in his *De Rerum natura,* two thousand years ago, and point out that scientific thought has not advanced greatly beyond the conceptions of the poet.

Lucretius, in the beginning of his poem, lays down the principle that nature carries on her operations by imperceptible particles which are separated from each other by spaces, empty and vacant. He urges that there must have been, and that there must be eternal matter; otherwise all things before this time would have been utterly reduced to nothing, and whatsoever objects appear would have been reproduced from nothing. Our first principle is that nothing can be produced from nothing. We insist upon the existence of void spaces between atoms, otherwise motions could not take place. All space is unbounded for if it were bounded it must have some extremity: it appears that there cannot be an extremity of any thing unless there be something beyond which may limit it. One should compare Lucretius with Einstein. The Roman philosopher appears to have antedated the German philosopher and his theory of relativity.

The poet's thoughts seem to have been put into scientific expression by the electron hypothesis which postulates that the ether of space is not a continuous medium, but is of a grainlike structure. Water seems to be a continuous medium, but on analysis is found to be made up of molecules and atoms of hydrogen and oxygen.

In the course of less than fifty years — since Franklin's study of electricity — the subject of electricity has made the greatest advances of any of the sciences, and it is now their leader: what other subject can point to such fecund theories and practical employments? The advance of electrical science seems to be typified by the release of a giant from restraining bonds, which did not entirely limit his great powers, but which concealed even more marvellous possibilities. For nearly half a century the subject of electricity was considered with respect to its behavior on metals: its practical employments had been in connection with conductors, metallic or fluid. Faraday discovered the influence which a current of electricity could exercise outside its metallic conductor, when it was started, or stopped, and called this influence, electromagnetic induction. He found that magnetism was a predominant feature in this outside influence, and he laid the foundation of the great modern practical employments of electricity. It seemed twenty years ago that we had reached a culminating point in the applications of electricity; it was difficult to see how the efficiency of the dynamo—an apparatus due to the laws discovered by Faraday — could be improved; it had reached an efficiency of over eighty percent; telegraphy and telephony had been standardized; only comparatively small improvements were in sight, no great electrical discovery was forecast. Indeed one of my students regretted that he had been born so late: the opportunity had passed to make an electrical name.

A great advance was to come from studies of the manifestations of electricity in freer media than metallic conductors — in rarified air and gases. In this advance we have returned to the field which occupied Franklin's mind — the phenomena of electrical sparks, of lightning discharges. If he could have seized the meaning of the northern lights what a revelation of a future advance would have been given him! If, however, a vision should be accorded to him, from some lofty height, of the manifestations of the X-rays, of the workings of the wireless telegraph he might humbly say, "My theory of electricity receives its consummation." If he should return to the earth today he would see in the modern electron theory, taken as a whole, an exemplification of his one fluid theory of electricity, but there is no evidence that he ever thought of any individual particles of electricity — the modern electrons. He attributed electrical attractions or repulsions to excess or deficits of a fluid. An electrical charge had no resemblance in his mind to a swarm of bees. We have advanced from his generalized view to a most prolific study of the minute constituents of an electrical charge.

I once stood with a distinguished English physicist at a lookout on the steeple of St. Bride's church in London, on Lord Mayor's day, and gazed with him at the streaming of people through the streets below, and through the gates to the closes. "What a representation of the molecular theory of gases," said my companion, "these streams of humanity afford." We see how the average motion of the individual is lost in a flow or a combined pressure. Perhaps if we could look closer into an electrical current we should see individuals.

Radioactivity, or to coin a new word, electronactivity, is the most important advance in electricity since the time of Franklin. We seem now to be provided with a high powered microscope by which we can observe the motion of particles of electricity: the objective is in our mind's eye. Electronactivity has enormously increased our conceptions of molecular activity. I have remarked that in the former prevalent theory of gases we conceived only of motion in straight lines — orbital movements were not considered; and there was no thought of magnetism or, indeed, of electricity in the molecular theory of gases. Forces of attraction bound atoms together in molecules and there the entity of both the atom and the molecule stopped. Now we think of an infinitesimal world in which electromagnetism plays the most important rôle: all atoms are accompanied by electrons. The diameter of an atom is that of a circle the centre of which is that of a nucleus, the radius of which is the distance to the farthest accompanying electron. We think of an atomic universe, in which there are suns and planets — the orbital movements of the electrons about the central nuclei has its analogies in the movements of the electrons; when there is a change in these movements there is a radiation of energy which occurs when the electron passes from a less stable orbit to a more stable one. A consideration of the energy changes in this operation is embodied in what is known as Planck's law, and it seems as if a new light has dawned in spectrum analysis. In this analysis it has been difficult to conceive of motions of atoms which apparently give rise to the arrangements of spectral lines. The idea of electrons circulating about the atoms gives an important clue to these arrangements — or series spectra — and the attention of spectroscopists is now largely devoted to the study of this idea.

We have seen what an important part the X-rays have played in the development of the subject of electro-activity. They have revealed the electron, and have been revealed themselves. These rays cannot be called the X-rays, for they are known to be light rays of very small length which are situated at the present limit of the ultra-violet end of the light spectrum, or rather of the electrical spectrum. In order to understand the steps which have led to their identification it is necessary to dwell upon the phenomenon of interferences of waves of light. This phenomenon is exhibited in the display of brilliant colors on the soap bubble, and on polished sea shells, such as the abalone shell found on the Pacific coast. The colors are due to the interferences of waves produced by thin films or layers. When, in the train of waves the crest of a wave is exactly superposed upon the trough of that of one of the same wave length, light, or effect of these waves is extinguished. When the crests of waves of the same length are superposed there is added light or added physical effects. The colors on the surfaces of various thin films or layers are not regularly placed, and vary with the thickness or irregularity of the films of layers. The colors, or effects, however, can be arranged in the order observed in the rainbow or in the spectrum produced by a glass prism, by reflecting a beam of light from a surface on which many fine lines have been ruled, very near together, by a diamond point. These interference spectra have almost entirely displaced the use of the glass prism spectrum, investigated by Sir Isaac Newton. They not only disproved his theory of light but made his method of observation obsolete. We are now, perhaps, in a condition to understand the discovery of the X in the appellation originally given by Röntgen to the rays he discovered. Laue, a German physicist, suggested the reflection of these rays from the surface of a crystal in order to see whether interferences might not arise from the infinitely small distances between the molecules in the surface layers of a certain crystal. This suggestion was carried out by Professor Bragg and his son, two English physicists, by an electrical method, and an interference spectrum was found by means of which the wave length of the X-rays was calculated; it is closely that of the unit of wave length, the angstrom, in the region of the ultra-violet light spectrum; the X-rays have not ceased to be an electrical phenomenon. When an X-ray picture is taken, not only the particles of silver on the photographic plate or film are stimulated, but the atoms of all surrounding matter are excited, and their electrons give off secondary X-rays, or radiations. The limit of the ultra-violet waves, and that of the size of the ultimate particles of what we call matter, have been greatly elucidated by the X-rays. When one is asked what is the direction of the advance of electricity in the future one can reply with a measure of confidence that it will be in the field of electronactivity. And the position of

Franklin as a historic figure in the development of this field has been given a new radiance, and his unifying mind would seem to find philosophical satisfaction in the modern theory that physical science is the science of energy, and that light, heat, electricity and magnetism are merely different forms of energy.

(new p to follow)

CHAPTER XXVII

THE TASK OF A FUTURE FARADAY

IF, indeed, one will arise, his task will be far greater than that of his predecessor, Michael Faraday, who may be said to have opened the richest mine in the history of science. His discoveries led to the invention of the dynamo, the telephone, and the principles of wireless telegraphy. He had at his command two agencies which were unknown to Franklin, and for the want of which the progress of the latter was completely blocked, the electric current and the galvanometer, which disclosed the relations of electricity and magnetism.

Faraday investigated the flow of electricity as a whole and did not enter into questions of possible particles of the flow — a flow which seemed to be analogous to that of a fluid — except that of a manifestation outside the conveyer of the fluid, a magnetic action. The supposed electric fluid differs, however, from all other fluids in causing flows outside its own conduits — that is in unconnected pipes. When an electric current starts a current of induction is excited in neighboring independent circuits, this momentary current is in opposite direction to that of the exciting one; when the latter suddenly ceases, another current of induction arises in the neighboring circuits, which flows in the same direction as that of the original current. It is as if spectators had a momentary alarm, and shrank away, and afterward thronged in the direction of the charmer. These momentary currents of induction were also considered as flows of a fluid. There was no speculation in the time of Faraday in regard to the individual particles of such flows. The discovery of these momentary effects of an electric current, outside the wires — the conductors — in which it was circulating, was the great discovery of Faraday: it has led, I have said, to the invention of the dynamo, the telephone, wireless telegraphy — in fact to almost all the modern applications of electricity. Faraday worked his mine with a mind of genius; but his task was lighter than that of the physicist who may strive to explain the working of the individual particles of the electric current, and who looks farther into the mysteries of electricity. Ampere, who developed the laws of electromagnetism, especially in relation to the attraction and repulsion of currents—laws which find their exemplification in electric motors—said, before developing the laws of electromagnetism which underlaid the attraction or repulsion of currents and those of magnets, "The impossibility of submitting directly to experiment the infinitely small portions of the electric current obliges one necessarily to proceed from experiments made with conductors of finite size, and it is necessary to satisfy two conditions: that the observations may be susceptible of great precision, and that they may be suitable to determine the mutual action of two infinitely small portions of these conductors." It is reported that Ampere did not use the apparatus he devised to prove the truth of his mathematical calculations: so sure was he of their truth. Both Faraday and Ampere treated electric currents, even in infinitely small portions of conductors, as something analogous to flows of fluids. Faraday could conceive of the mechanism of electrical conduction through liquids, and he stated the laws of electrolysis—separations of constituents of liquid conductors, movements of these so-called ions—which are used today by all chemists. When the electrical current, however, left the liquid for the metallic conductor which connected the poles of the battery, he could form no idea of internal motion in such a conductor; it would seem that there must be something analogous to the motion of the ions in the liquid portion of the circuit, but it was impossible to trace it. There was a magnetic action, but this was shown also by the portion of the current which flowed through the liquid.

When we reflect upon the varied actions of the dynamo currents we find grounds for believing that there is a movement of individual particles in a conductor which is aroused by their passing near the magnetic particles of iron. Their existence, indeed, in an electric circuit has been shown by the possibility of forcing them out into a vacuum, by the application of electromotive force upon a wire which they have made hot by their activity. The electron, or individual particle of electricity, in the electric current has now been discovered; but its action in conductors carrying such a current is less understood than in rarified gases. There are those who are inclined to believe that we have arrived at the culminating point of the curve which represents electric progress *per se* — to use Franklin's favorite expression. Such point out that the dynamo is highly efficient — there is little more to be desired; the telephone has settled down to a commercial routine; wireless telephony is showing its limitations. It seems as if there must be a period of brick laying by a multitude of comparatively humble workers, but under the direction of architects — some one of whom may prove to be the coming Faraday.

When we think of the great achievements in electrical science we should also consider the depths of our ignorance. Reflect upon the phenomena of electrical inductance: how do the movements of the electrons in the exciting circuit cause the apparently quiescent ones in the neighboring independent circuits to start in an opposite direction when the exciting circuit is made, and then to fall back into quiescence until the latter ceases, when they again start into momentary activity? When we closely examine this phenomenon of induction, we perceive that it is a consequence of the law of the conservation of energy: if the currents of induction did not flow in the manner observed work would be obtained without the expenditure of work.

Turning to the subject of magnetism — which can never be separated from that of electricity — how does the combined or continuous movement of the electrons in the electric current which is wrapped about a bar of iron maintain or communicate a more or less permanent state of activity of the electrons about the iron atoms? How different from the attitude of the inducing electrons! Moreover, one magnet can induce an indefinite number of other magnets and suffer no loss of magnetism. There is a mysterious setting-off action, as if the electrons were dislodged from a state of quietude and set into orbital or vibrating movement by a trigger-like effect which has no equivalence in the change of atomic energy. It would seem as if the atoms of the iron with their accompanying electrons were moved from an unorganized state into an organized one with their axes placed in one direction. Ampere, we have said, supposed electric currents circulating in the molecules of iron. He concluded that the currents must circulate in the molecules and not outside and around them; for if they circulated around them, meeting resistance would generate heat, and there would be a constant expenditure of energy to maintain them. Maxwell remarks that by confining the circuits to the interior of the molecules, within which nothing is known about resistance, we may assert without fear of contradition that the current meets with no resistance. We reflect, however, that if there is no resistance the currents would be infinite; for if they obeyed Ohm's law which states that the strength of an electric current is equal to the electromotive force divided by the resistance we should have the electromotive force divided by zero — which is infinity; if the electromotive force is also zero, we should have an indeterminate result. The hypothesis, however, of electric currents circulating in the molecules of magnetised iron and steel is exceedingly convenient for the mathematical analyst. The discovery of the electron has led to the supposition that there is a somewhat similar particle, which is called a magneton, the activities of which in the molecules of the magnetic metals account for their magnetic property.

In speaking of radium I remarked that the problems of the magnet seem to me more inscrutable than those of radium. Magnetic force which was practically disregarded in Franklin's time is now the leading subject of inquiry in electricity. A bit of radium loses its potential energy slowly but continuously in time. One bit of radium is not influenced by companionship with another. The two can be moved nearer each other, or farther apart without any resultant effect.

A steel magnet, on the contrary, preserves its magnetism indefinitely if it is kept at a constant temperature, and free from shocks or vibrations. It is probable that a load stone, dug up two thousand years ago, has its pristine magnetic quality today — if kept under the conditions outlined above. The Faraday of the future will be tempted to follow the manifestations of electricity in the open — in the northern lights — and will thus return in a measure to the field of study of Franklin; but there again the field has been enormously extended. The electron, besides exhibiting what we have come to consider peculiar electrical properties, has shown its activities in the atomic world. The lines in the spectra of metals and gases are supposed to be due to the orbits of the electrons about heated atoms. In the study of spectra we are led to the study of the stellar universe, and we can say to the future Faraday, *Sic*
itur *it~~e~~r ad astra.*

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